Jet Propulsion Laboratory
California Institute of Technology

JPL/NASA and Space Exploration

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July 4, 2018

Topics

- Introduction:
  - NASA
  - JPL
  - Natural Space Environments (NSE) Group
  - Myself

- Solar System Exploration
  - Mars Exploration Program
    - MSL
    - M2020
  - Europa
  - Psyche

JPL is part of NASA and Caltech

JPL

- Federally (NASA)-owned “Federally-Funded Research and Development Center” (FFRDC)
- University (Caltech)-operated
- >$2 billion business base
- ~6,000 employees
- 177 acres (Includes 22 acres leased for parking)
- 139 buildings and 36 trailers
- 673,000 net square feet of office space
- 906,000 net square feet of non-office space (e.g., labs)

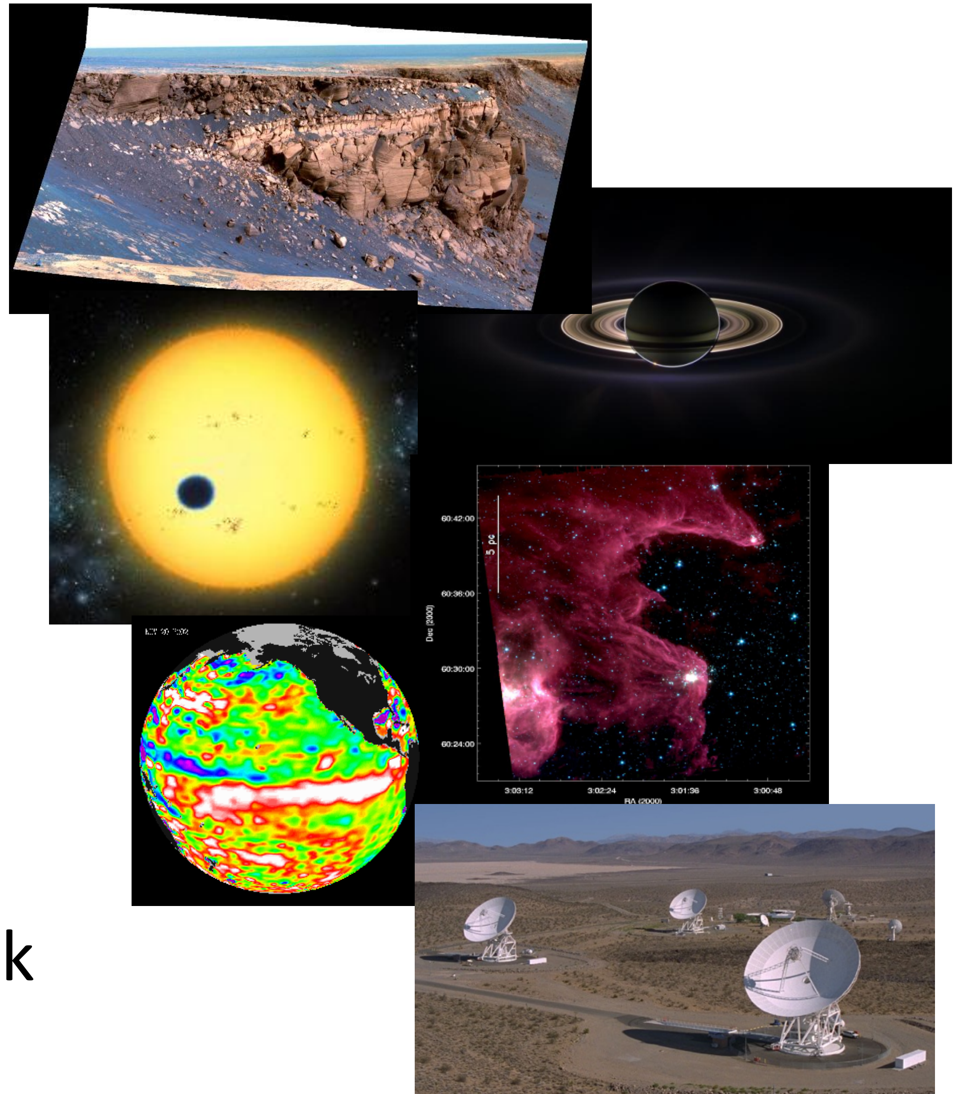
NASA

JPL

CalTech

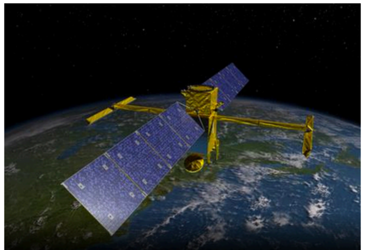
JPL's primary mission is robotic space exploration

- Solar system
- Exoplanets
- Astrophysics
- Earth Science
- Interplanetary network

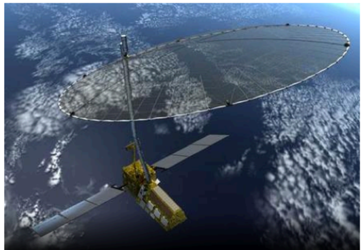


Thirty-nine spacecraft and instruments across the solar system (and beyond) – as of 2017

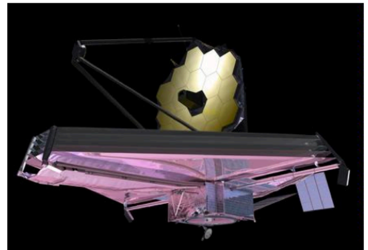
> 10 Future Missions



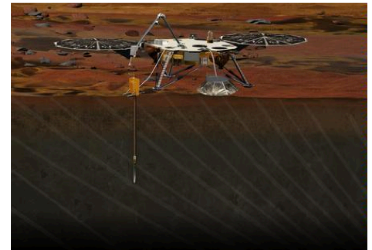
SWOT
Surface Water and Ocean Topography



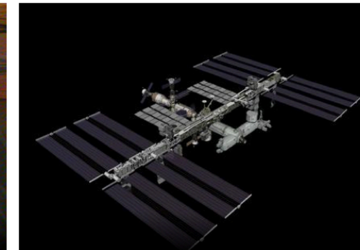
NISAR
NASA-ISRO Synthetic Aperture Radar



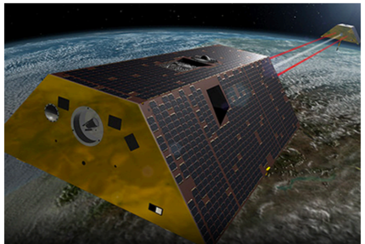
MIRI
Mid-Infrared Instrument



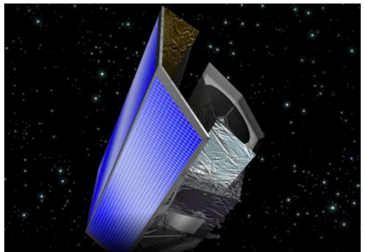
InSight
Launched in May



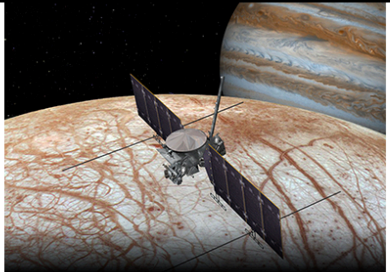
CAL
Cold Atom Laboratory



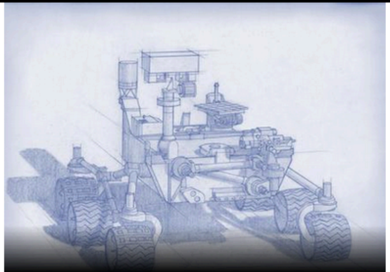
GRACE-FO
Gravity Recovery and Climate Experiment Follow-On



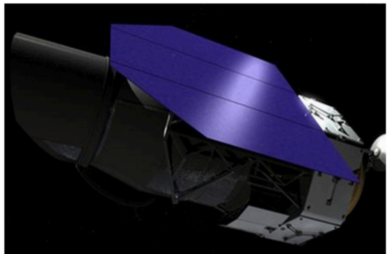
Euclid



Europa Clipper



Mars 2020



WFIRST
Wide Field Infrared Survey Telescope

Psyche (planned)

"The decision to implement WFIRST will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for information purposes only."

Pre-Decisional Information -- For Planning and Discussion Purposes Only

JPL's Natural Space Environment Group

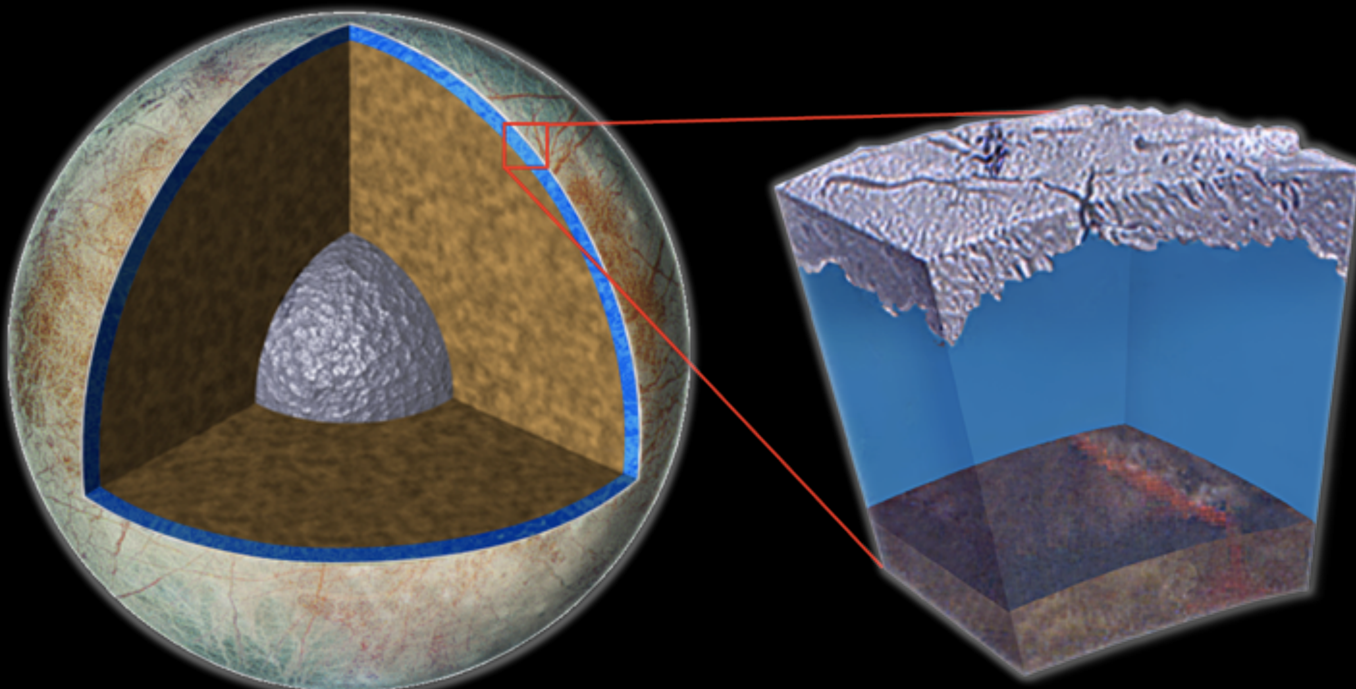
- Supports all JPL space-flight missions for the space environments and effects
  - Radiation (environment, shielding, charging, ….),
  - Meteoroids, Debris (MMOD)
  - Atomic Oxygen, Dust,
- Is the JPL lead for nuclear planetology (Gamma ray and neutron spectroscopy)
- Tasked with understanding environment hazards, to direct the design of robotic spacecraft we send into the solar system
- We strive to contribute to model development or improvement
  - e.g. models of solar proton fluence, outer-planet trapped radiation, meteoroids

Things on plate

- Group supervisor/Chief Technologist
- Europa Clipper (also radiation science team)
- Europa Lander COncept (Pre-project) – Radiation Lead
- Planned Psyche Mission – Science Co-I
- MSL – Science collaborator
- NASA CLT/TDT
- Space Weather Architecture WG
- Thesis advisor for two PhD students
- MDAP, SURP, ….
- ……

Europa Mission

The Ocean That Beckons



*Europa, with its probable vast subsurface ocean sandwiched between a potentially active silicate interior and a highly dynamic surface ice shell, offers **one of the most promising extraterrestrial habitable environments**, and a plausible model for habitable environments beyond our solar system*

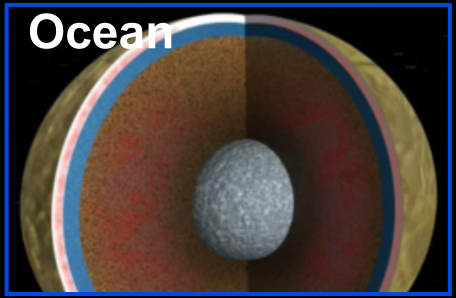
The Planetary Decadal Survey, 2011

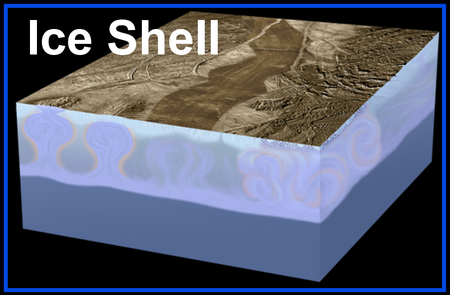
Achieving Decadal Science

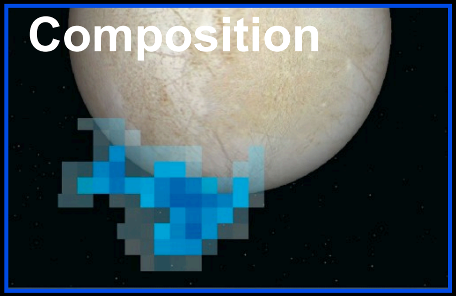
"The first step in understanding the potential of the outer solar system as an abode for life is a Europa mission with the goal of

- *Confirming the presence of an interior ocean,*
- *Characterizing the satellite's ice shell, and*
- *Enabling understanding of its geologic history"*

– The Planetary Decadal Survey, 2011

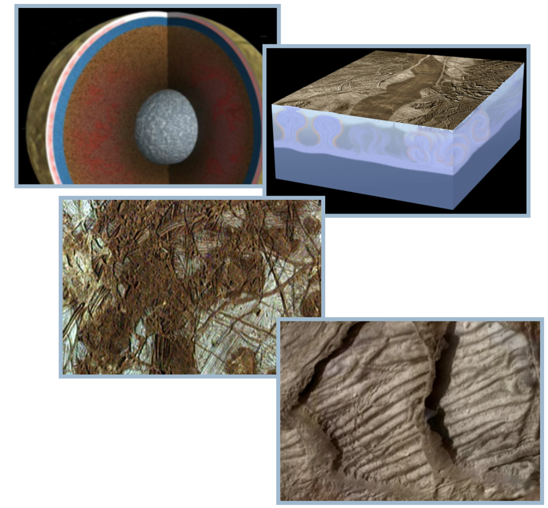




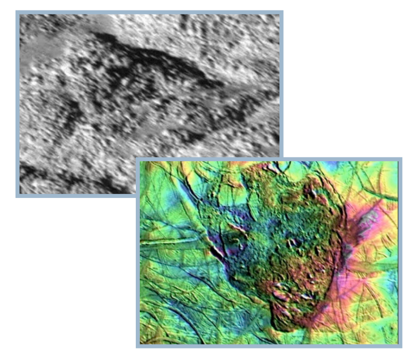


Europa Clipper Goals and Objectives

- ***Science Goal:*** *Explore Europa to investigate its habitability*
  - **Ocean & Ice Shell:** Characterize ice shell and subsurface water, including heterogeneity, ocean properties, and surface-ice-ocean exchange
  - **Composition:** Understand habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand formation of surface features, including sites of recent or current activity, and characterize high science interest localities

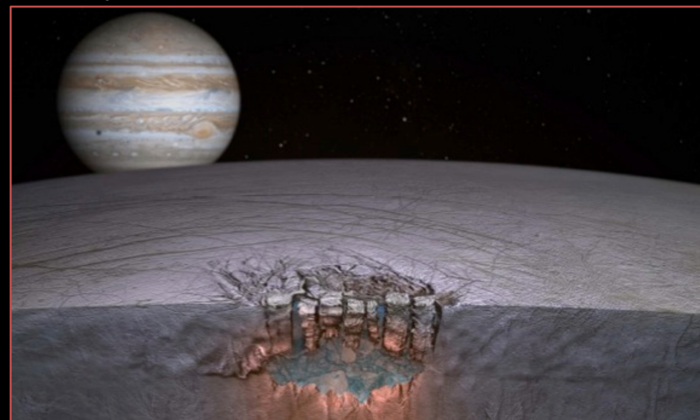


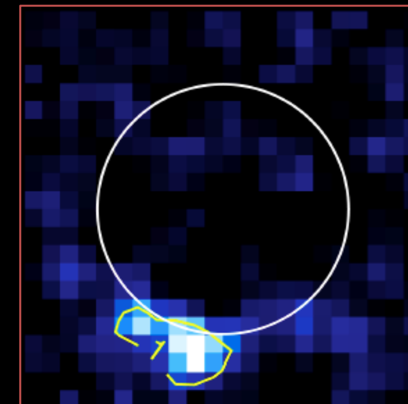
- ***Reconnaissance Goal:*** *Characterize Safe and Scientifically Compelling Sites for a Future Lander Mission to Europa*
  - Distribution of surface hazards, load-bearing capacity of surface, structure of the subsurface, and regolith thickness
  - Composition of surface materials, geologic context, potential for geologic activity, proximity of near surface water, and potential for active upwelling of ocean material



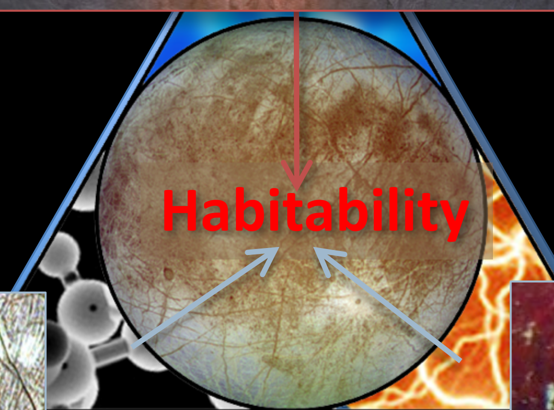
Europa: Ingredients for Life?

Water: Are a global ocean and lakes hidden by Europa's shell of ice?



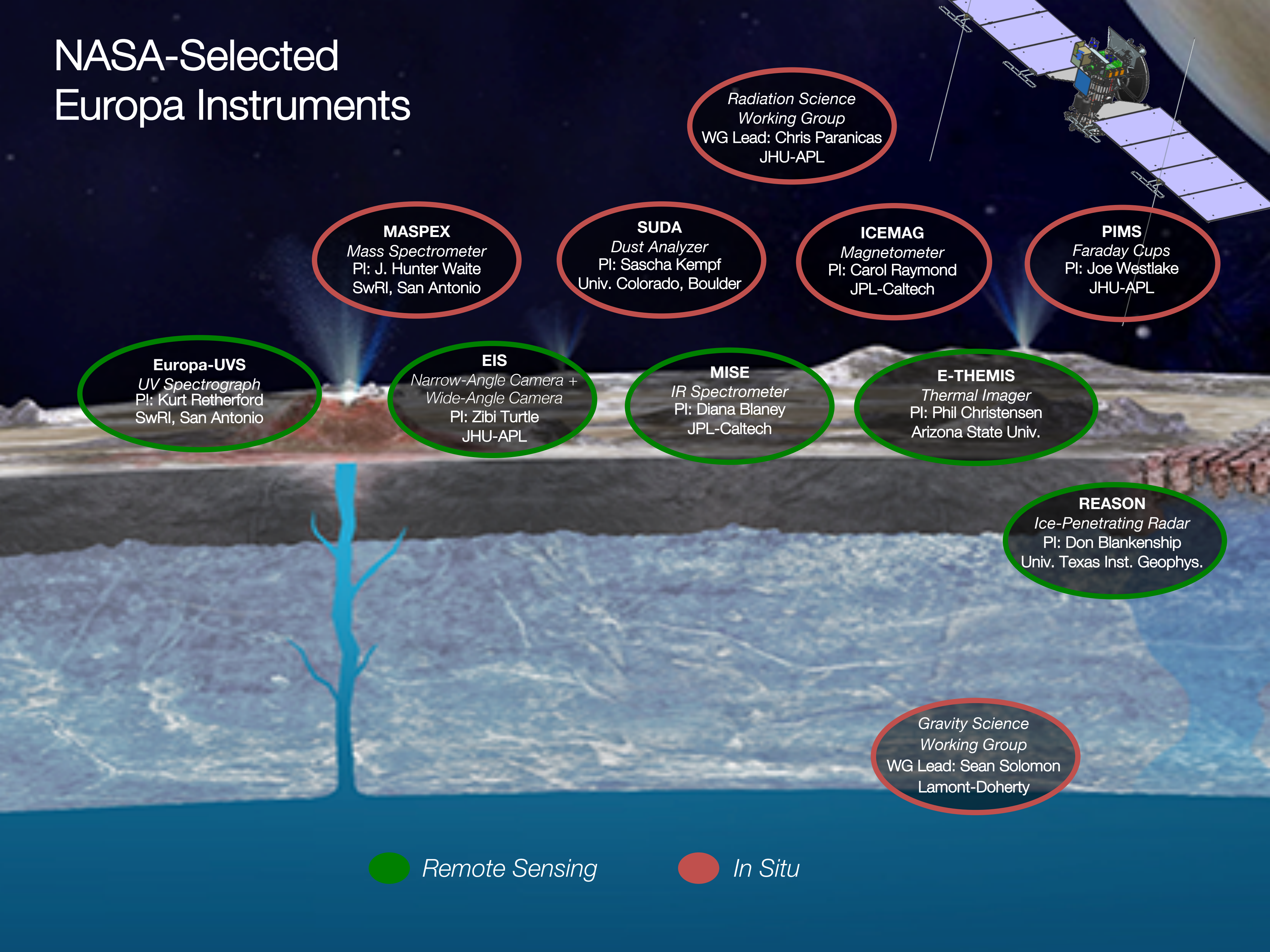


Plumes at Europa!
(Roth et al., 2013)

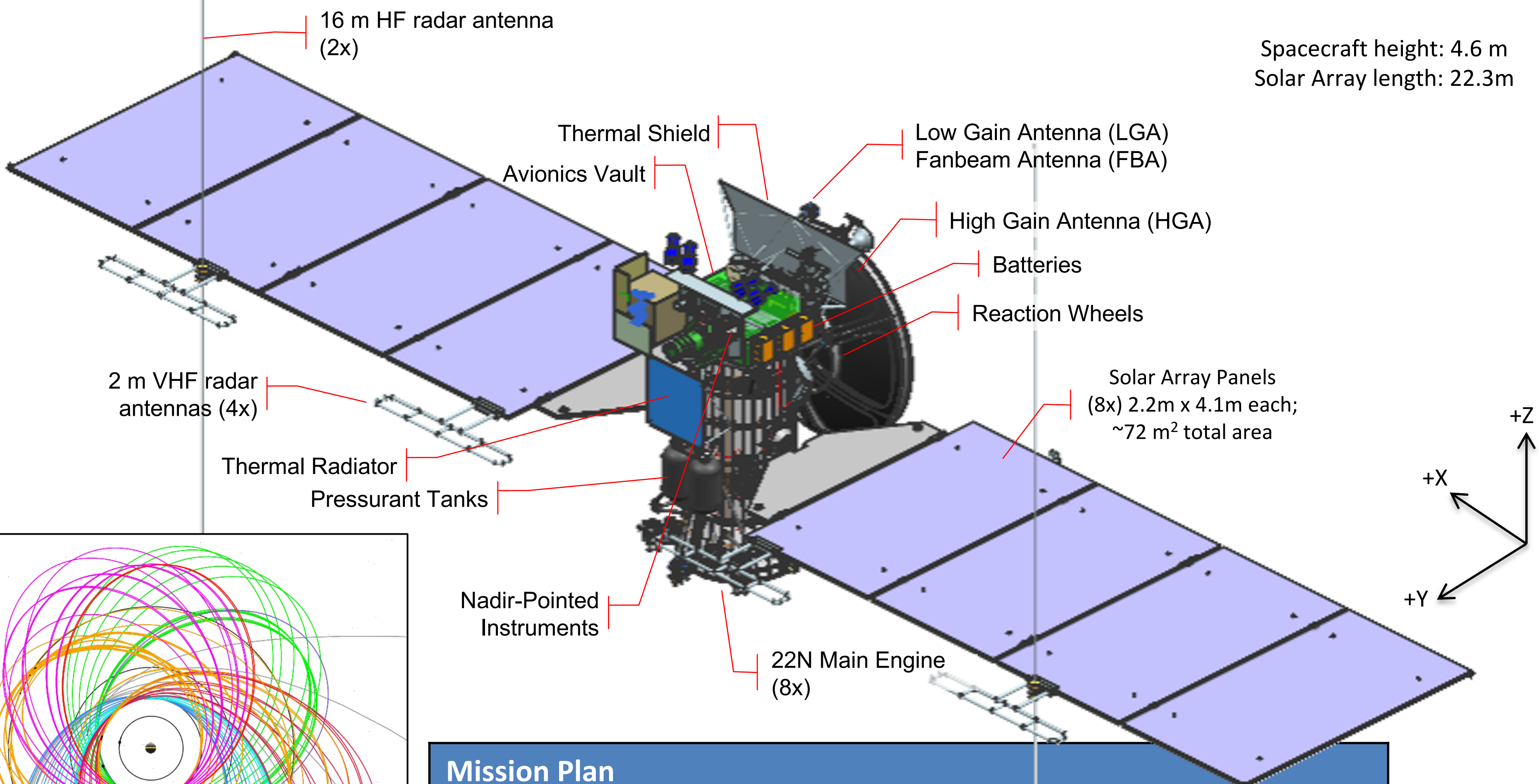


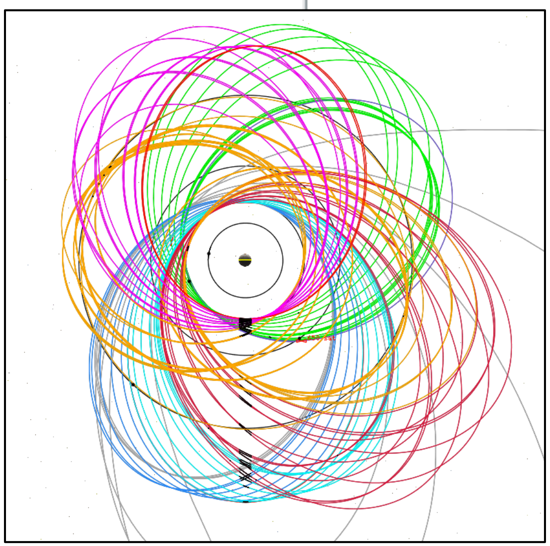
Chemistry: Do red surface deposits contain organics from below?

Energy: Can surface oxidants provide energy for metabolism?


NASA-Selected
Europa Instruments
Radiation Science
Working Group
WG Lead: Chris Paranicas
JHU-APL
MASPEX
Mass Spectrometer
PI: J. Hunter Waite
SwRI, San Antonio
SUDA
Dust Analyzer
PI: Sascha Kempf
Univ. Colorado, Boulder
ICEMAG
Magnetometer
PI: Carol Raymond
JPL-Caltech
PIMS
Faraday Cups
PI: Joe Westlake
JHU-APL
Europa-UVS
UV Spectrograph
PI: Kurt Retherford
SwRI, San Antonio
EIS
Narrow-Angle Camera +
Wide-Angle Camera
PI: Zibi Turtle
JHU-APL
MISE
IR Spectrometer
PI: Diana Blaney
JPL-Caltech
E-THEMIS
Thermal Imager
PI: Phil Christensen
Arizona State Univ.
REASON
Ice-Penetrating Radar
PI: Don Blankenship
Univ. Texas Inst. Geophys.
Gravity Science
Working Group
WG Lead: Sean Solomon
Lamont-Doherty
Remote Sensing
In Situ

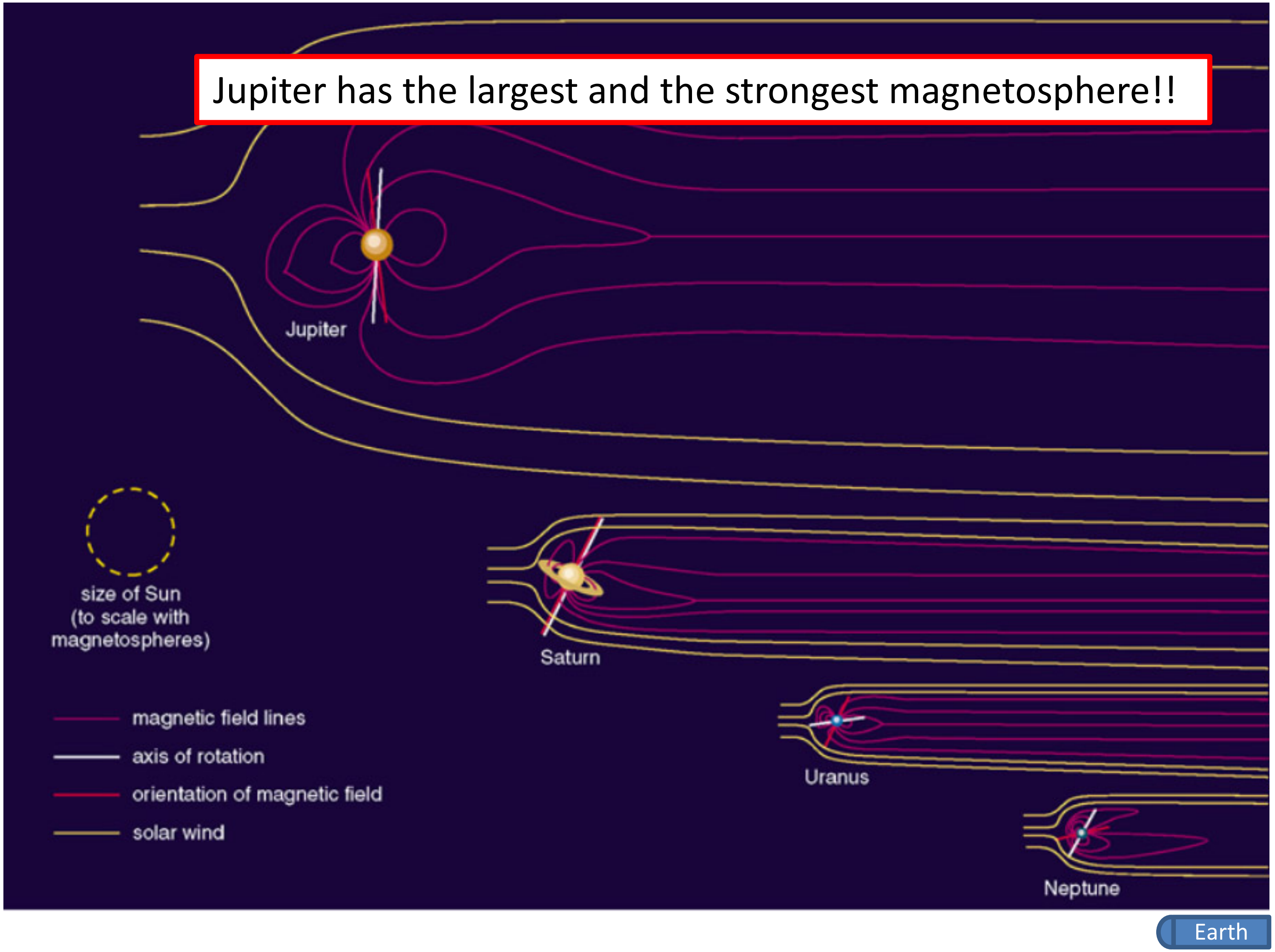
Europa Mission Concept Overview





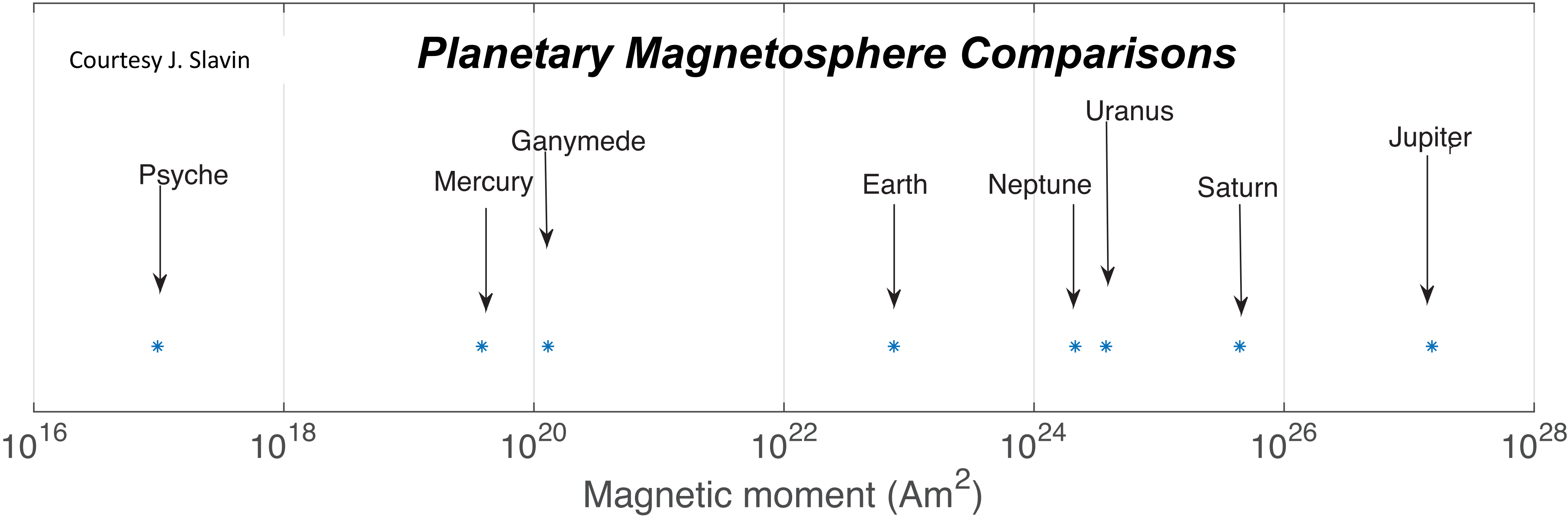
Mission Plan	
Earliest potential launch date	6 June 2022
Earliest Jupiter Arrival	5 Mar 2025 (if SLS launch)
Science Tour	~42 Europa Flybys in prime mission
Primary Mission End	6 Dec 2028 (Ganymede Impact)

Planetary Magnetospheres in the Solar System



Physical properties of the planets and the Sun.
Values are based on the HORIZON system
[Giorgini et al., 1996].

Planetary Characteristics



PHYSICAL PROPERTIES:	Earth	Jupiter	Saturn	Uranus	Neptune
Equatorial radius (km)	6378	71492	60268	25559	24766
Mass (kg)	5.97E+24	1.90E+27	5.68E+26	8.68E+25	1.02E+26
Semi-major axis (AU)	1	5.2	9.54	19.19	30.07
Sidereal day (hr)	23.93	9.89	10.61	17.14	16.7
Dipole tilt (deg)	11.3	9.6	0	58.6	47
Dipole offset (rp)	0.0725	0.131	0.04	0.3	0.55
Magnetic moment (G-R_p^3)	0.305	4.28	0.21	0.228	0.133

Jupiter's Magnetosphere

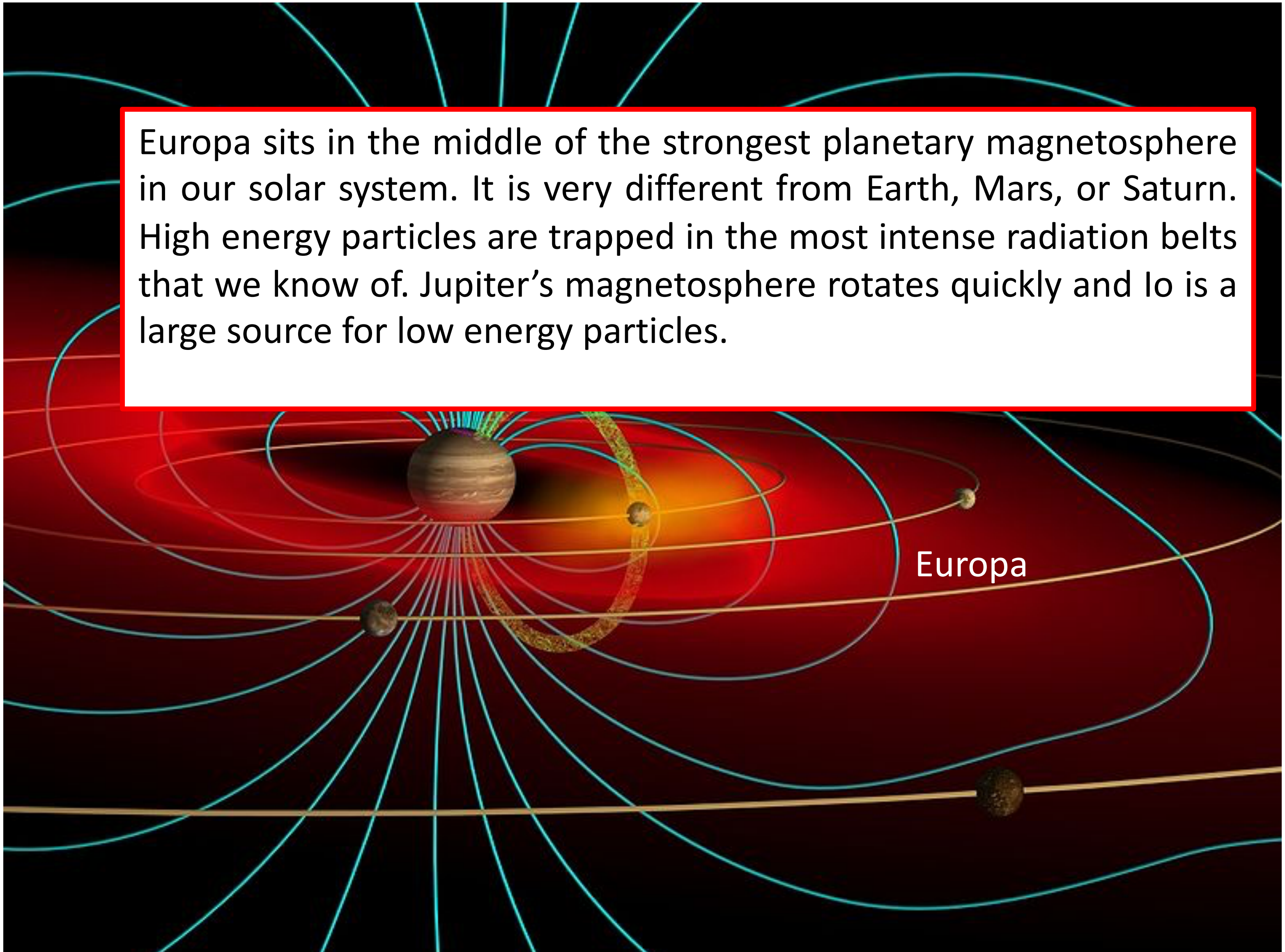
	Earth	Jupiter
Equatorial radius (km)	6.38×10^3	7.14×10^4
Magnetic moment (G-cm^3)	8.1×10^{25}	1.59×10^{30}
Rotation period (hr)	24.0	10.0
Aphelion/perihelion (AU)	1.01/0.98	5.45/4.95

- Jupiter is roughly 10 times the size of the Earth while its magnetic moment is 20,000 times larger.
- As the magnetic field at the equator is proportional to the magnetic moment divided by the cube of the radial distance, the Jovian magnetic field is proportionally 20 times larger than the Earth's.

The energy and flux levels of trapped particles in the Jovian system can be much higher than those at the Earth or in the interplanetary space

Jupiter

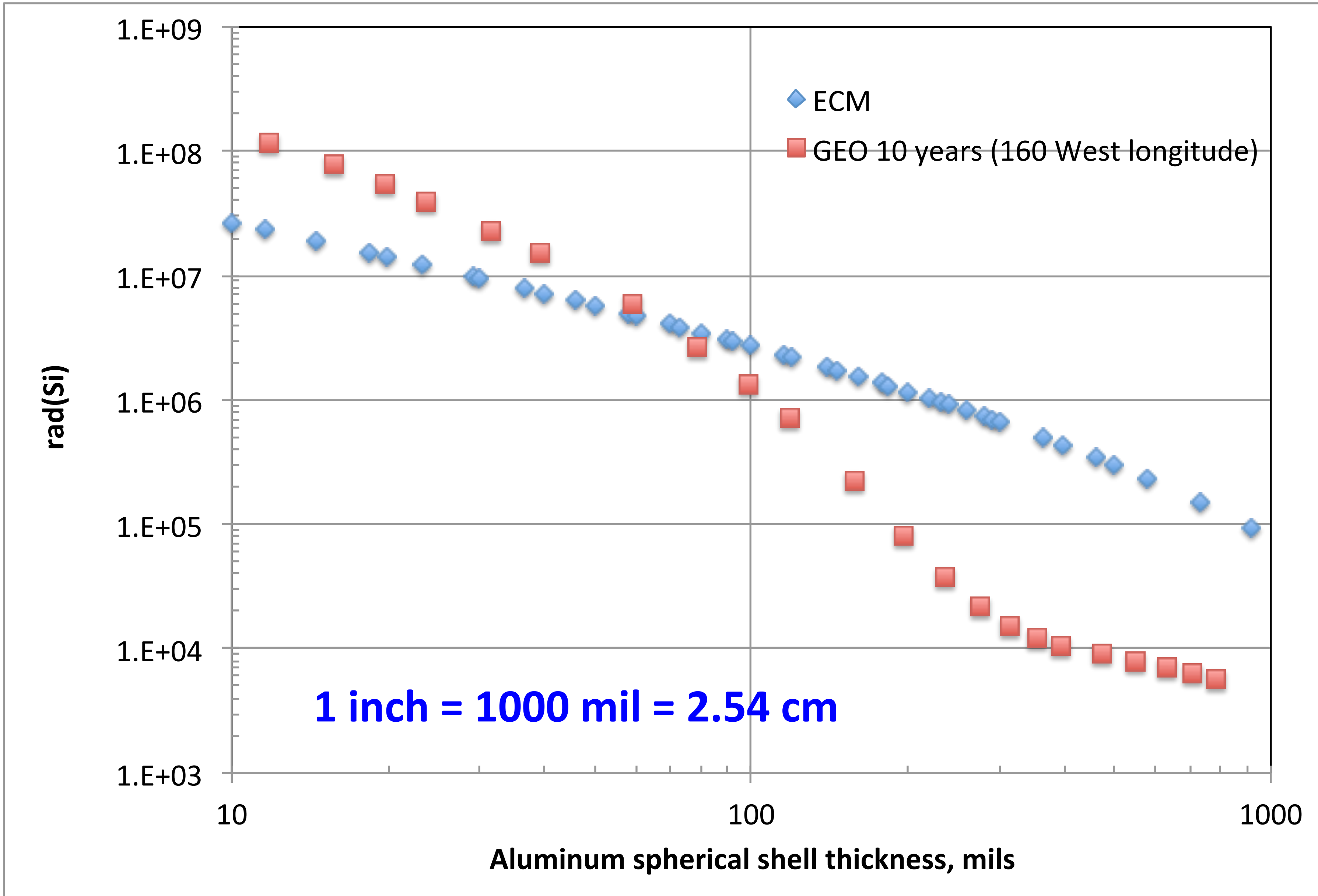
Europa sits in the middle of the strongest planetary magnetosphere in our solar system. It is very different from Earth, Mars, or Saturn. High energy particles are trapped in the most intense radiation belts that we know of. Jupiter's magnetosphere rotates quickly and Io is a large source for low energy particles.



Radiation Effects Concern Level

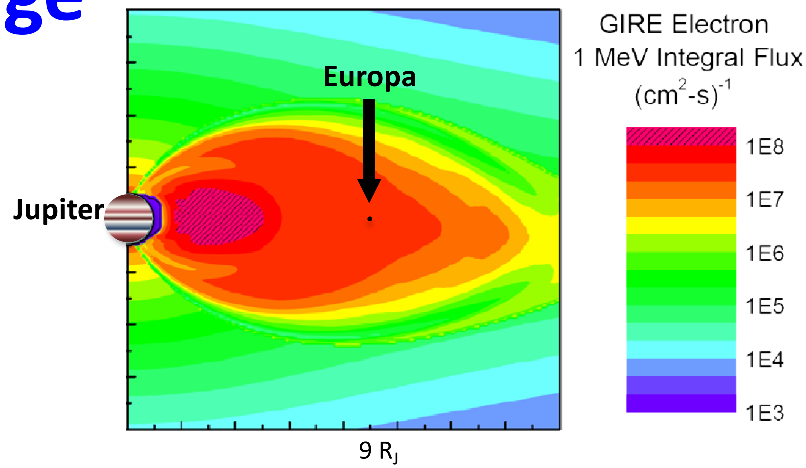
Effect	Concerns
Total Ionizing Dose (TID)	Very high compared to other NASA missions. Dominated by high energy electrons. Will require special attention for ECM.
Dose rate	Very high, especially during Europa fly-bys. Will require special attention for ECM. May reduce test time for ELDRS. Issue for sensitive instruments
Displacement Damage Dose (DDD)	10 to 100 times higher than other NASA missions. Could be important for optoelectronic devices at Jupiter.
Single Event Effects (SEE)	Typical level as other NASA missions. Trapped heavy ions at Jupiter are not significant issue for most electronics.
Charging	Internal charging is a major issue due to high electron flux. Will require special attention for ECM.
Transient or Secondary radiation	Important design consideration for sensors and detectors. Must include secondary particle due to high energy electron interactions with materials.

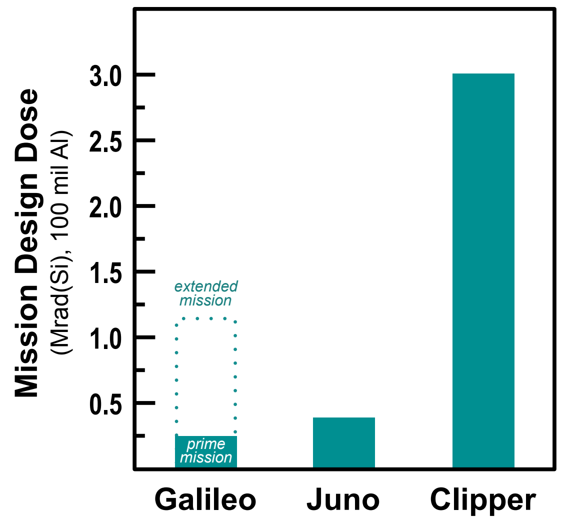
ECM versus GEO



Radiation: the Key Challenge

- Europa lies well within the Jovian radiation and plasma environment
- Total dose will be far higher than previous experience
- Meeting the challenge:
  - Minimize exposure through innovative trajectory design
  - Maintain conservative design margins (RDM of 2)
  - Use commercially available parts (300 krad(Si))
  - House electronics in Radiation Vault





SUMMARY
What's different about Jovian Environment?

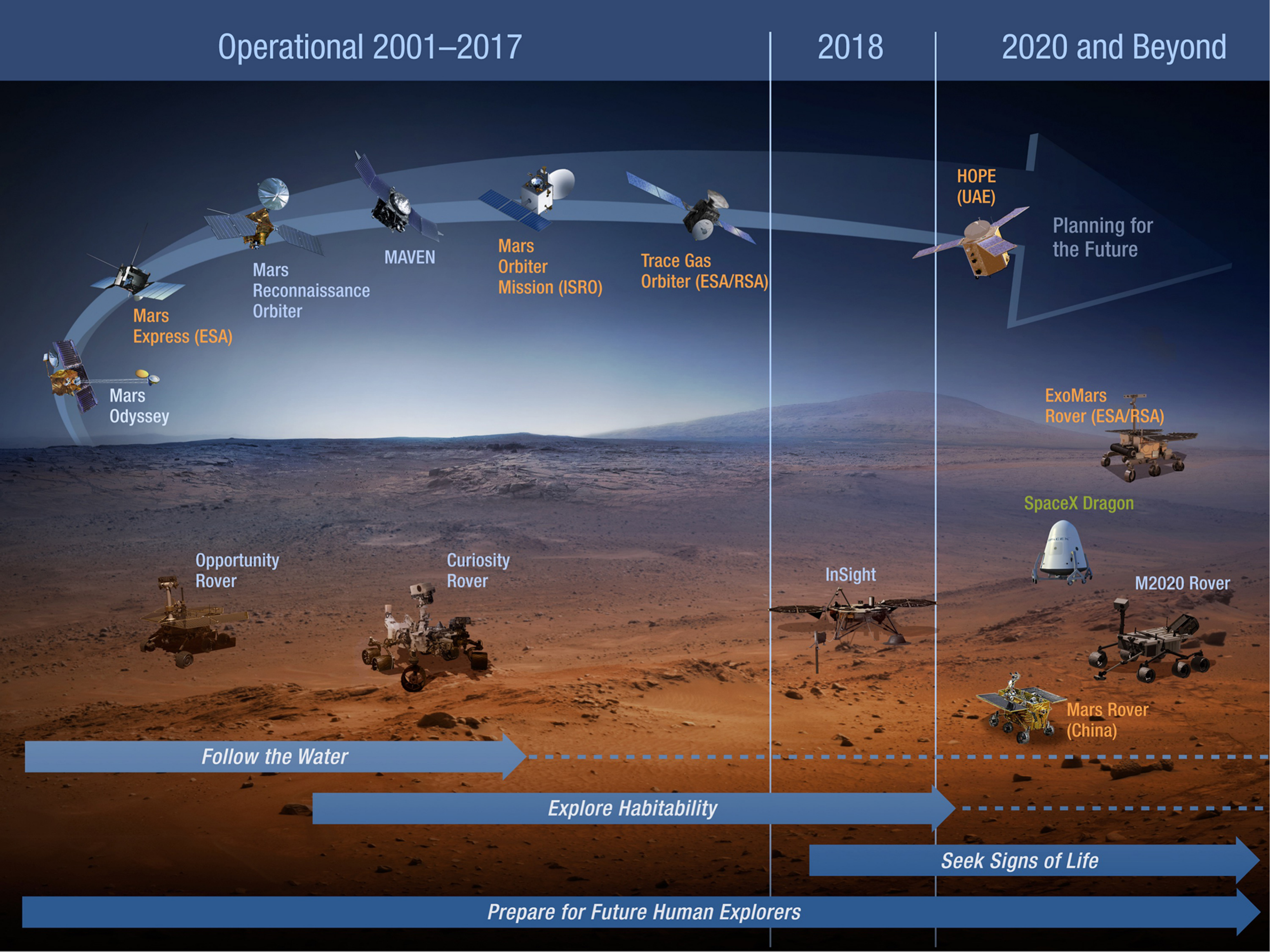
- Field is tilted ~10° tilt with respect to Jovian equator
  - Rotates with ~10-hour period – modulates radiation flux at Europa
  - Plasma co-rotates with ~120 km/s velocity at Europa
  - Io as a plasma source
- Expected mission total ionizing doses are substantially higher compared to other planetary or deep space missions

Shielding strategy needs system level attention to optimize the use of shielding mass

- The Jovian radiation environment is dominated by **high-energy electrons**
  - High-energy electrons can cause increased levels of internal electrostatic discharge
  - Secondary particles from high-energy electrons produce more transients and background noise in detectors and sensors

Special attention will be required to mitigate the radiation effects due to the high energy electron environment


NASA'S JOURNEY TO
MARS

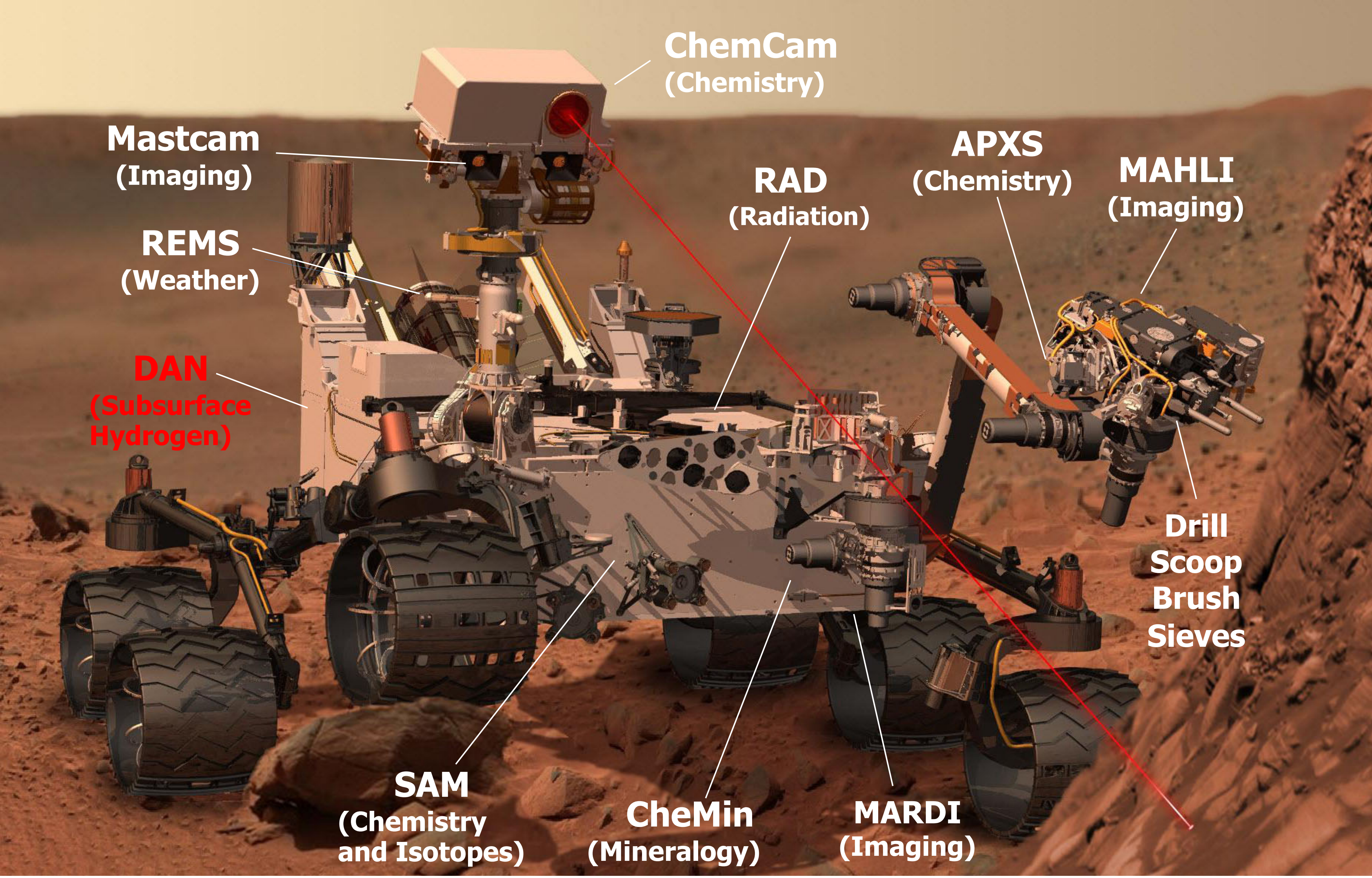

Operational 2001–2017
2018
2020 and Beyond
Mars Odyssey
Mars Express (ESA)
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA/RSA)
HOPE (UAE)
Planning for the Future
ExoMars Rover (ESA/RSA)
SpaceX Dragon
Opportunity Rover
Curiosity Rover
InSight
M2020 Rover
Mars Rover (China)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

MARS SCIENCE LABORATORY (CURIOSITY)

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

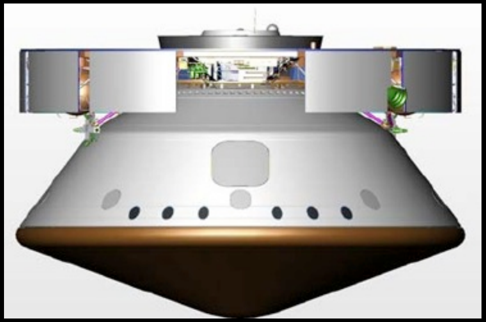
- Biological potential
- Geology and geochemistry
- Water and weather
- Radiation hazards

NASA/JPL-Caltech



Curiosity's Science Payload

Landing and Mobility



CRUISE/APPROACH

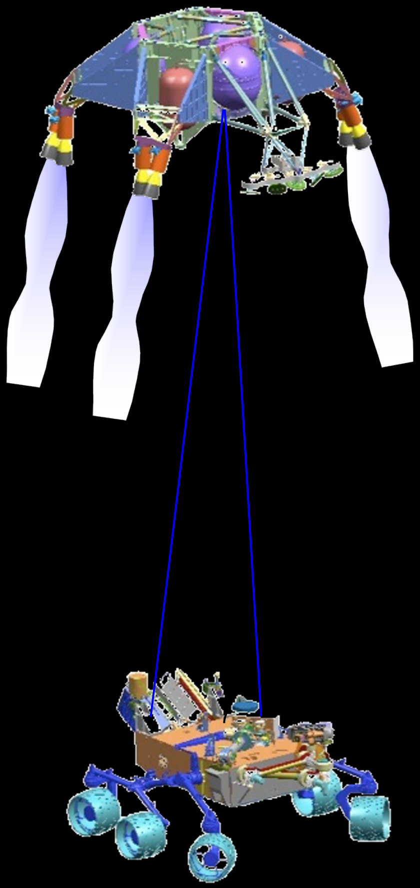
- 8-month cruise
- Arrived August 5th, 2012

LAUNCH

- Nov-2011
- Atlas V (541)

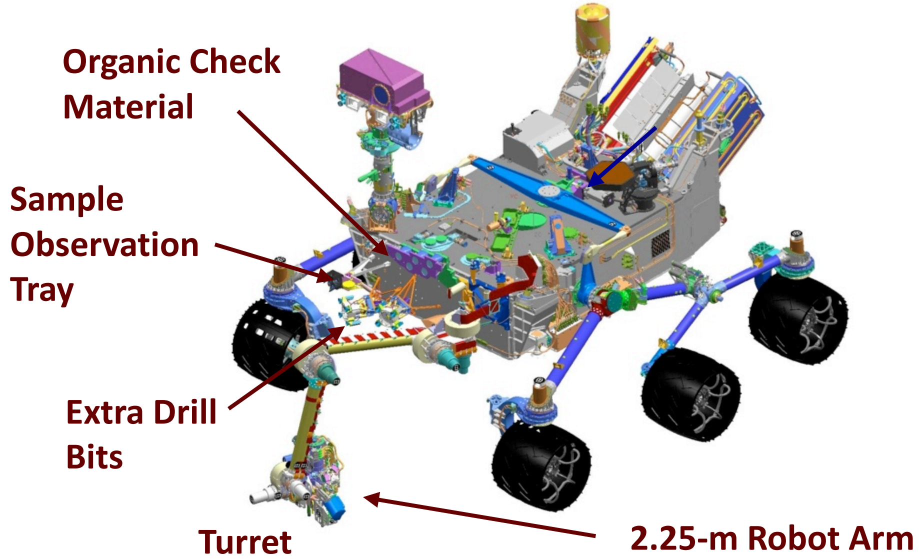
ENTRY, DESCENT, LANDING

- Guided entry and powered "sky crane" descent
- 20×25-km landing ellipse
- Access to landing sites ±30° latitude, <0 km elevation
- 900 kg rover

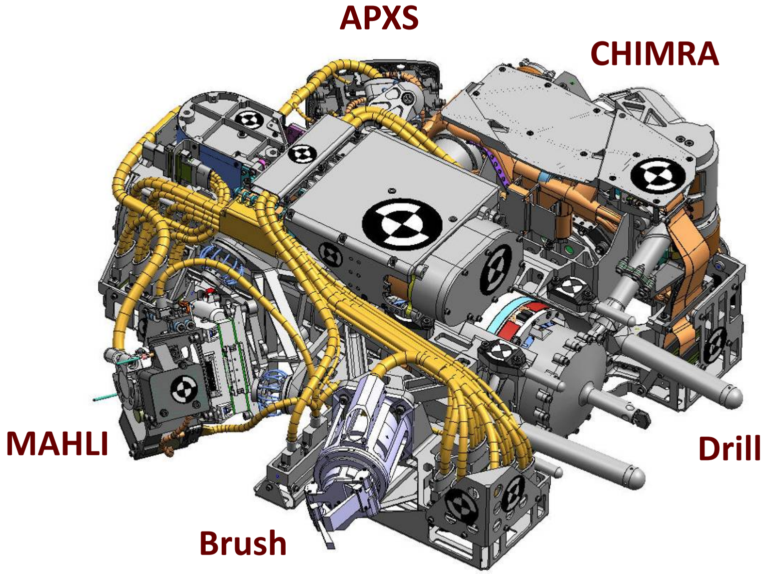


SURFACE MISSION

- Long-lived Plutonium power source
- Ability to drive out of landing ellipse, up 100 m per sol
- 84 kg of science payload
- Direct (uplink) and relayed (downlink) communication

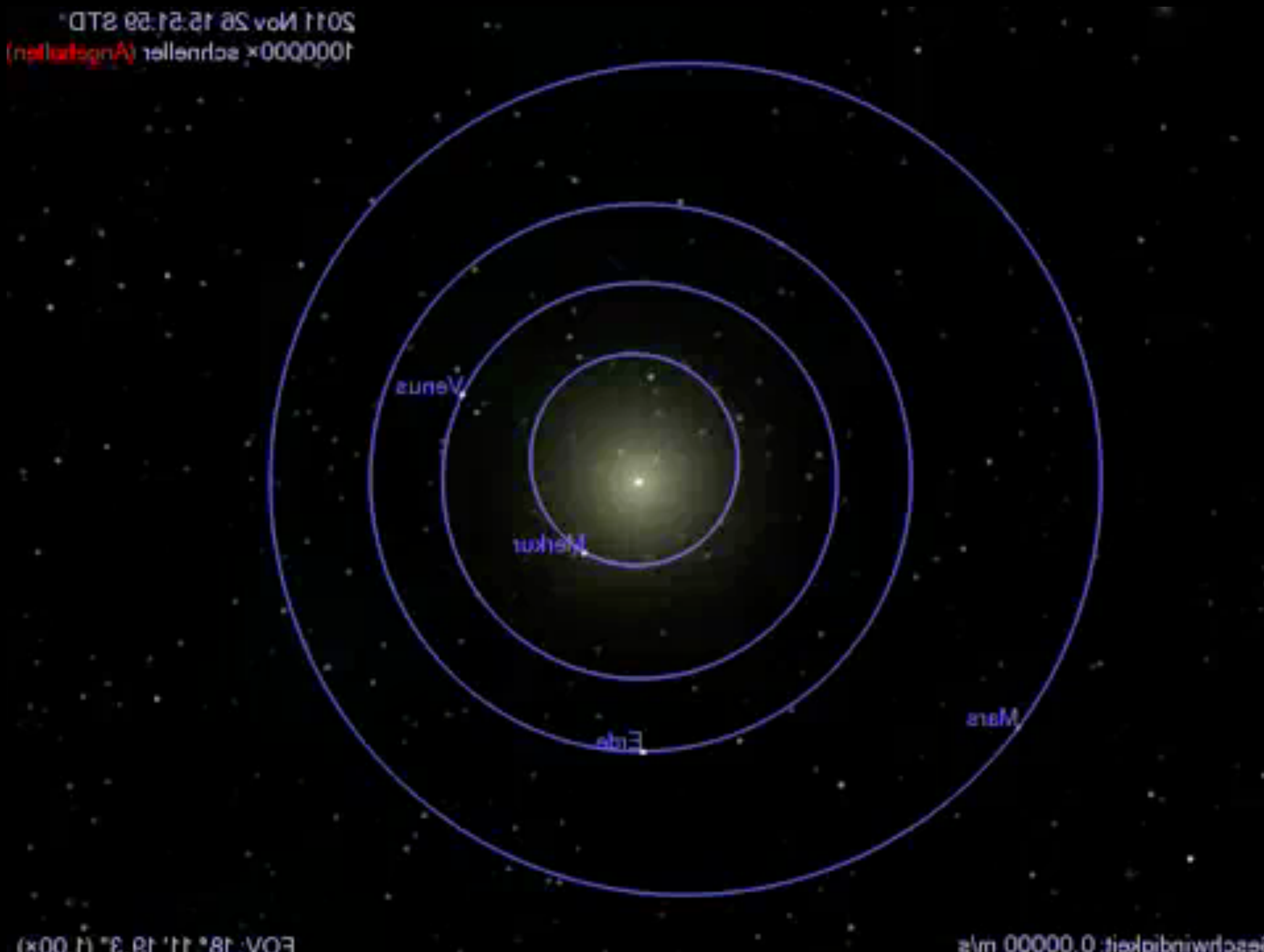


- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits



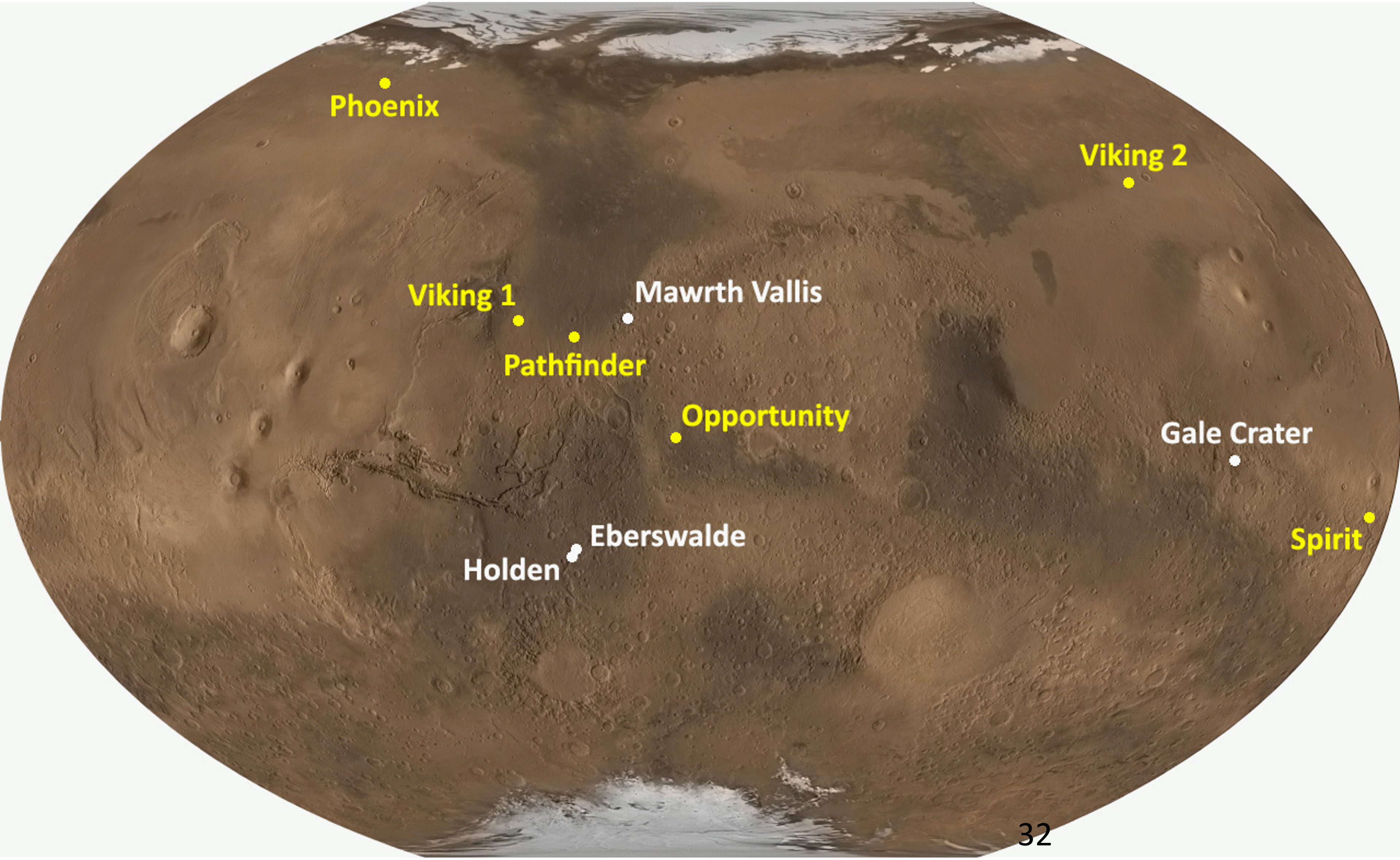
Curiosity's Sampling System

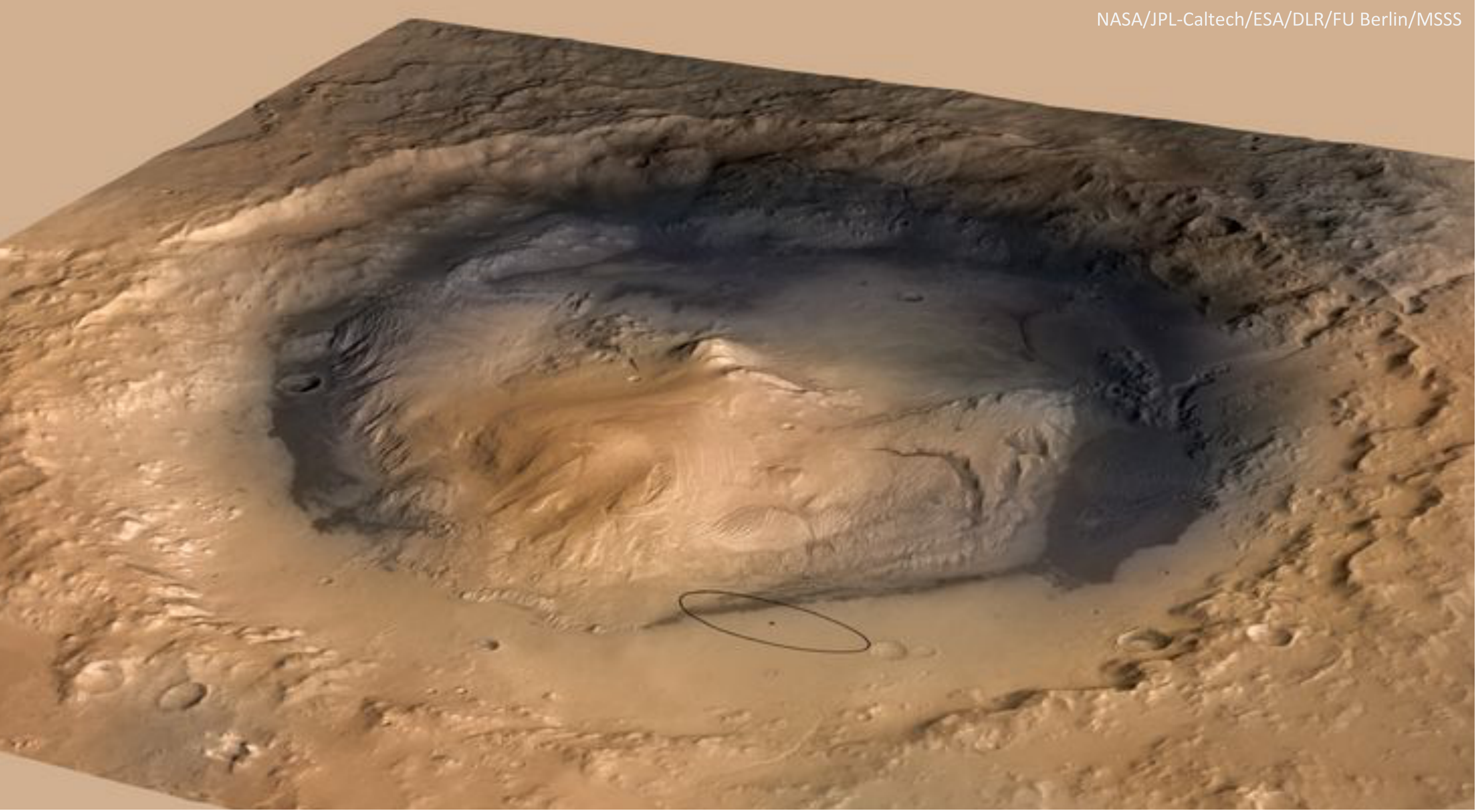
How do we get there?



Mars Landing Sites

(Previous Missions and MSL Final Candidates)





150-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound vary in mineralogy and texture, suggesting that they may have recorded environmental changes over time.

CURIOSITY

Kicking up dust just prior to landing

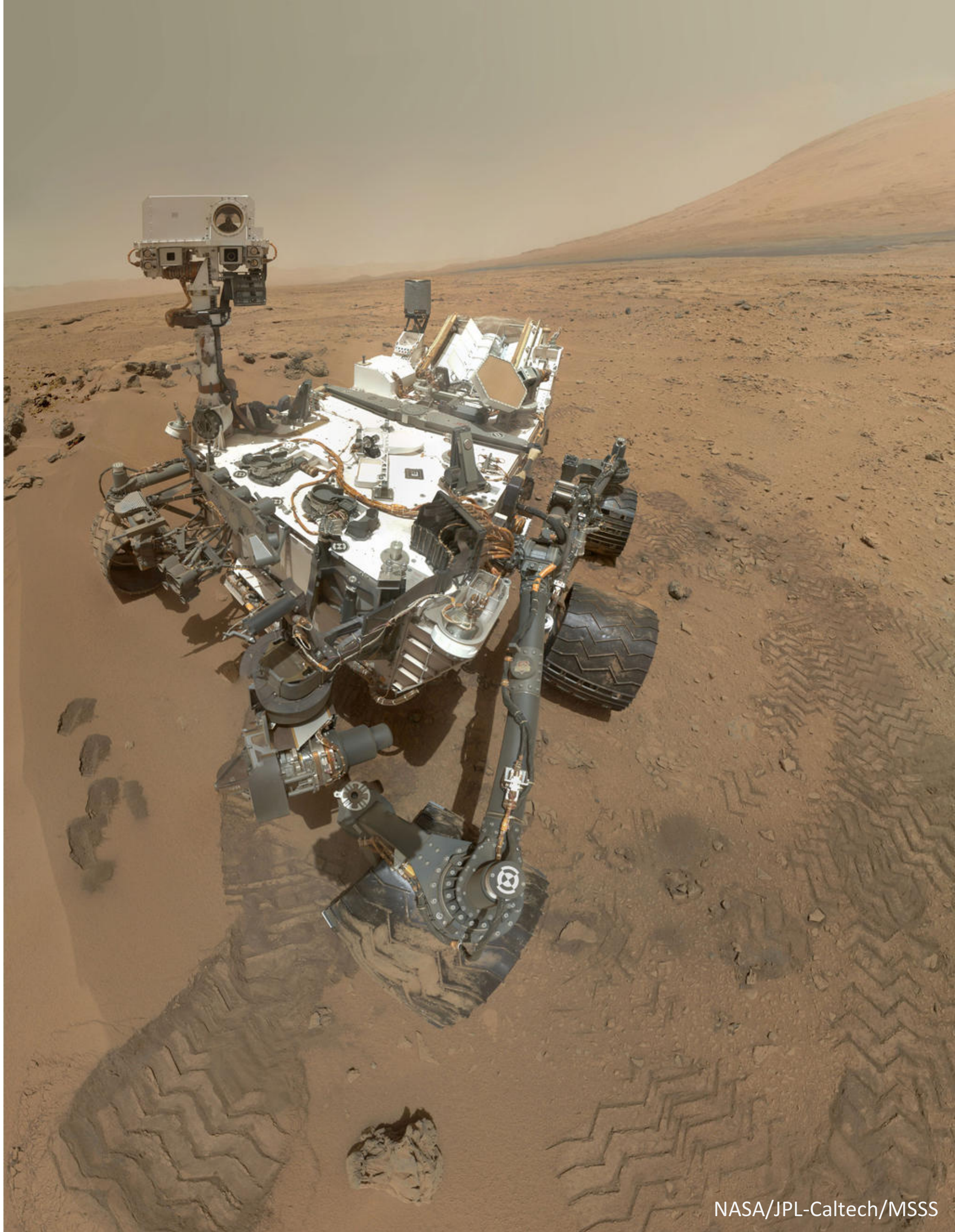
August 5, 2012: "Touchdown confirmed."
"Time to see where our Curiosity will take us."

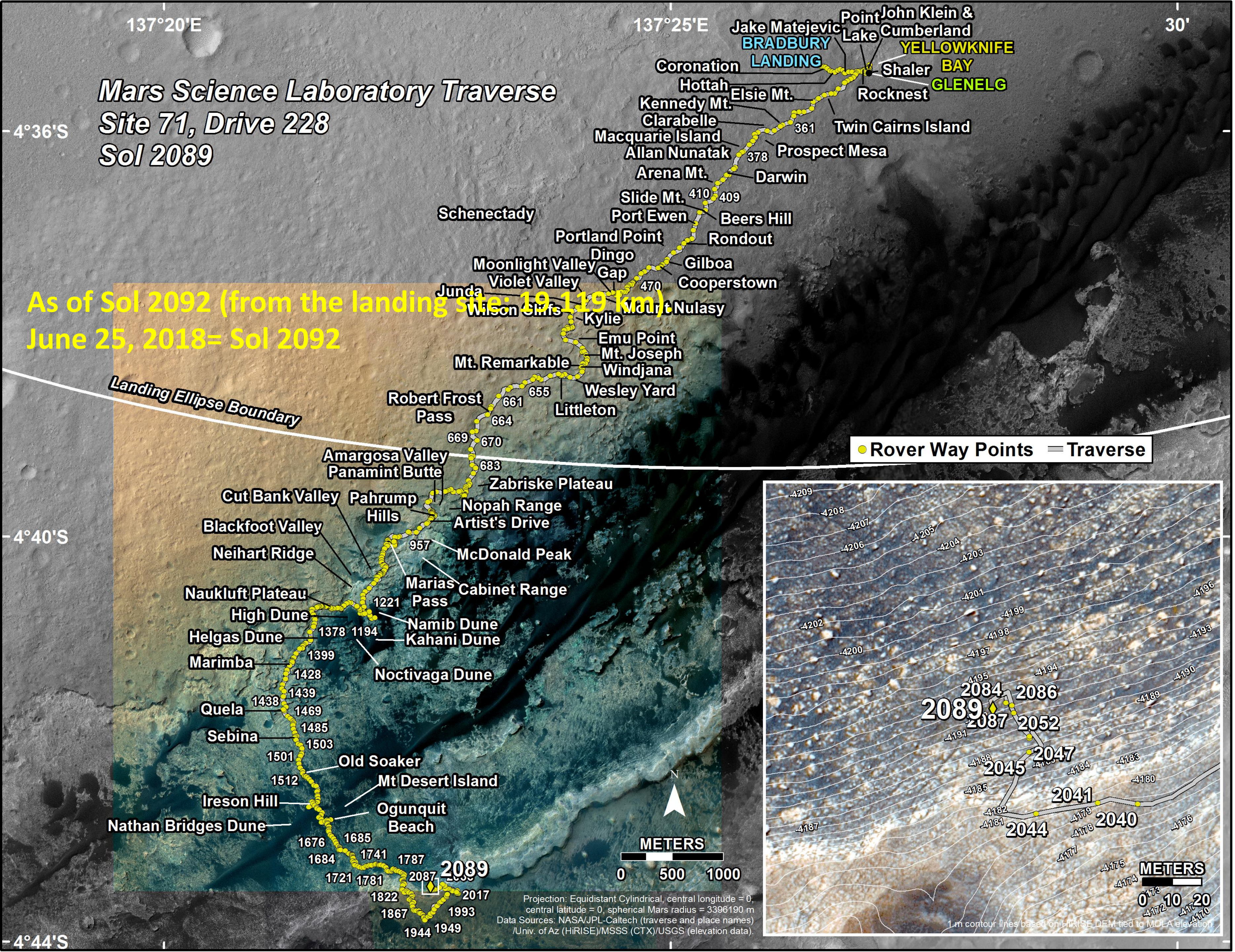
Curiosity self-portrait at Rocknest

Assembled from 55 MAHLI images

Shows four scoop trenches and wheel scuff

CURIOSITY



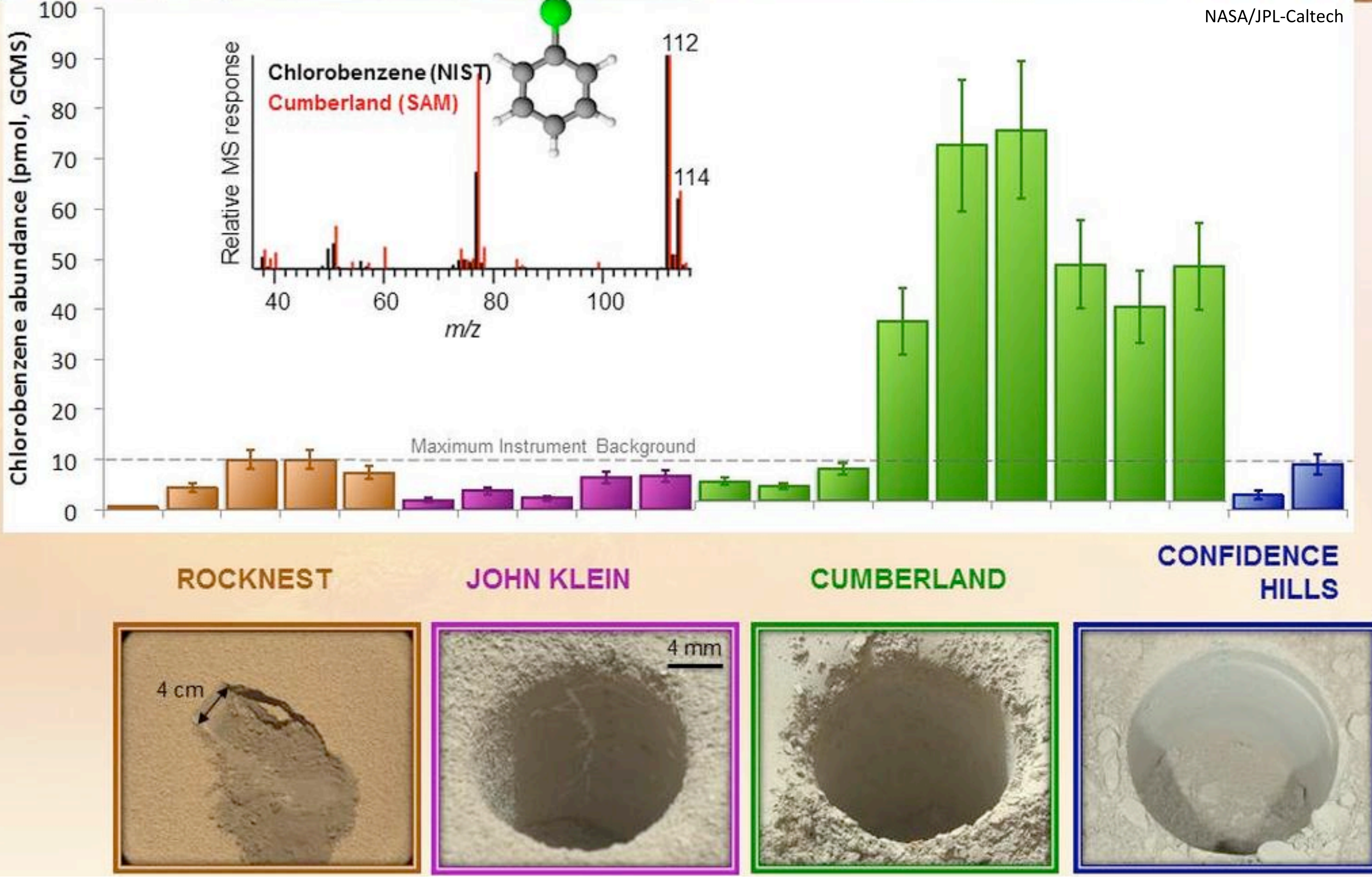


Mars Science Laboratory Traverse
Site 71, Drive 228
Sol 2089
As of Sol 2092 (from the landing site: 19.119 km).
June 25, 2018= Sol 2092
137°20'E
137°25'E
30'
4°36'S
4°40'S
4°44'S
Jake Matejevic
Point Lake
John Klein & Cumberland
BRADBURY LANDING
YELLOWKNIFE BAY
GLENELG
Coronation
Shaler
Hottah
Elsie Mt.
Rocknest
Kennedy Mt.
Clarabelle
Twin Cairns Island
Macquarie Island
Prospect Mesa
Allan Nunatak
Arena Mt.
Darwin
Slide Mt.
Beers Hill
Port Ewen
Schenectady
Portland Point
Rondout
Dingo Gap
Gilboa
Moonlight Valley
Violet Valley
Cooperstown
Junda
Wilson Cliffs
Mount Nulasy
Kylie
Emu Point
Mt. Joseph
Mt. Remarkable
Windjana
Wesley Yard
Robert Frost Pass
Littleton
Landing Ellipse Boundary
Amargosa Valley
Panamint Butte
Zabriske Plateau
Cut Bank Valley
Pahrump Hills
Nopah Range
Artist's Drive
Blackfoot Valley
McDonald Peak
Neihart Ridge
Marias Pass
Cabinet Range
Naukluft Plateau
High Dune
Namib Dune
Helgas Dune
Kahani Dune
Marimba
Noctivaga Dune
Quela
Sebina
Old Soaker
Mt Desert Island
Ireson Hill
Ogunquit Beach
Nathan Bridges Dune
361
378
410
409
470
655
661
664
669
670
683
957
1221
1378
1194
1399
1428
1439
1438
1469
1485
1503
1501
1512
1676
1685
1684
1741
1787
1721
1781
2087
2089
2017
1822
1993
1867
1944
1949
Rover Way Points
Traverse
METERS
0
500
1000
N
2084
2086
2089
2087
2052
2047
2045
2041
2040
2044
METERS
0
10
20
Projection: Equidistant Cylindrical, central longitude = 0, central latitude = 0, spherical Mars radius = 3396190 m
Data Sources: NASA/JPL-Caltech (traverse and place names) /Univ. of Az (HiRISE)/MSSS (CTX)/USGS (elevation data).
1 m contour lines based on HiRISE DEM tied to MOLA elevation

An Ancient Habitable Environment at Yellowknife Bay

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed
- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Furthermore, conditions were not strongly oxidizing.
- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur
- The presence of minerals in various states of oxidation would provide a source of energy for primitive organisms

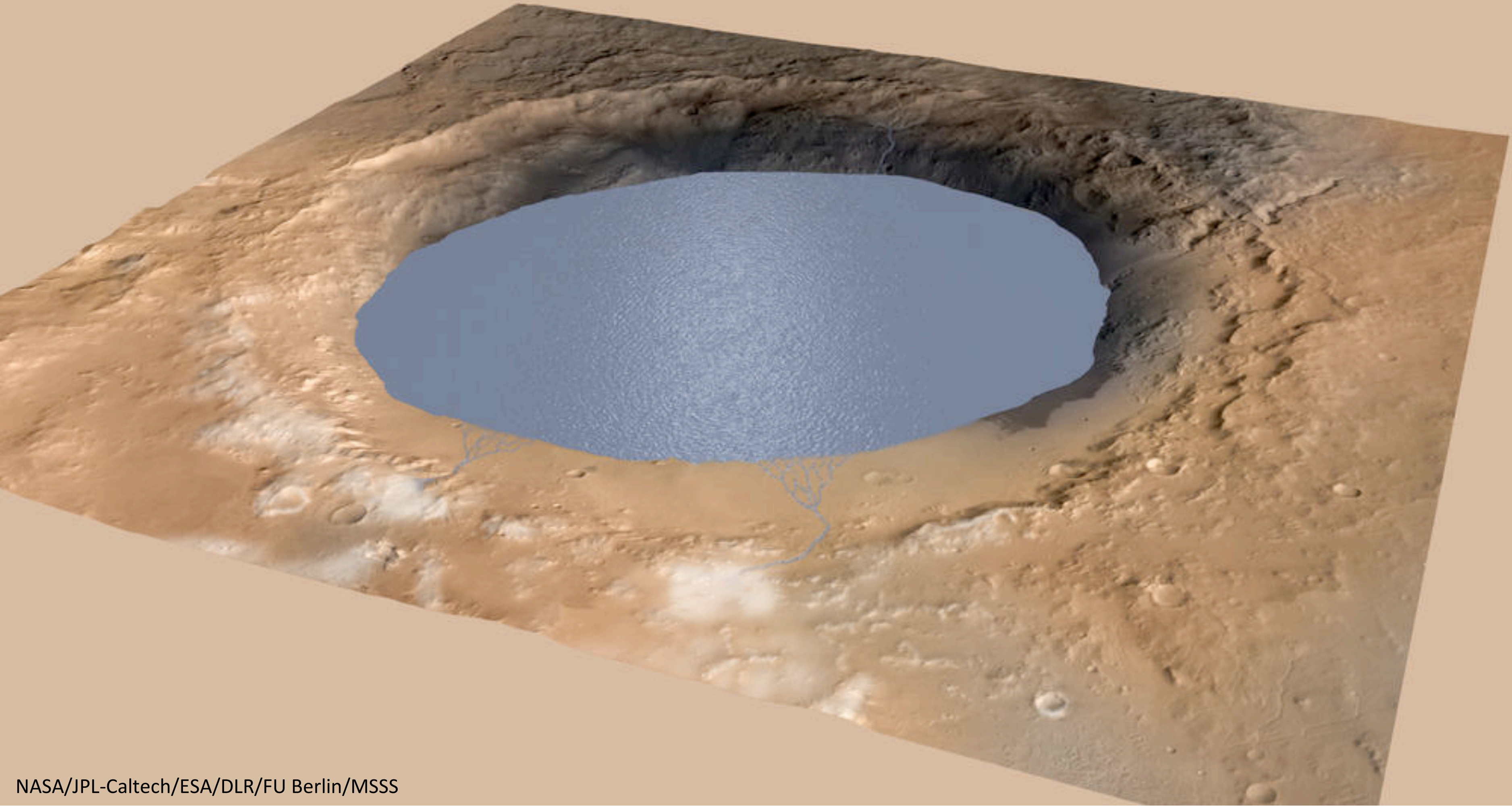
NASA/JPL-Caltech/MSSS



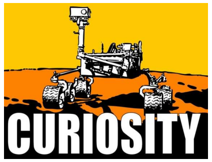
The organic chemical chlorobenzene was detected in the Cumberland drilled sample. The chlorine likely is derived from perchlorate in the sedimentary rock.

Notes on Organics

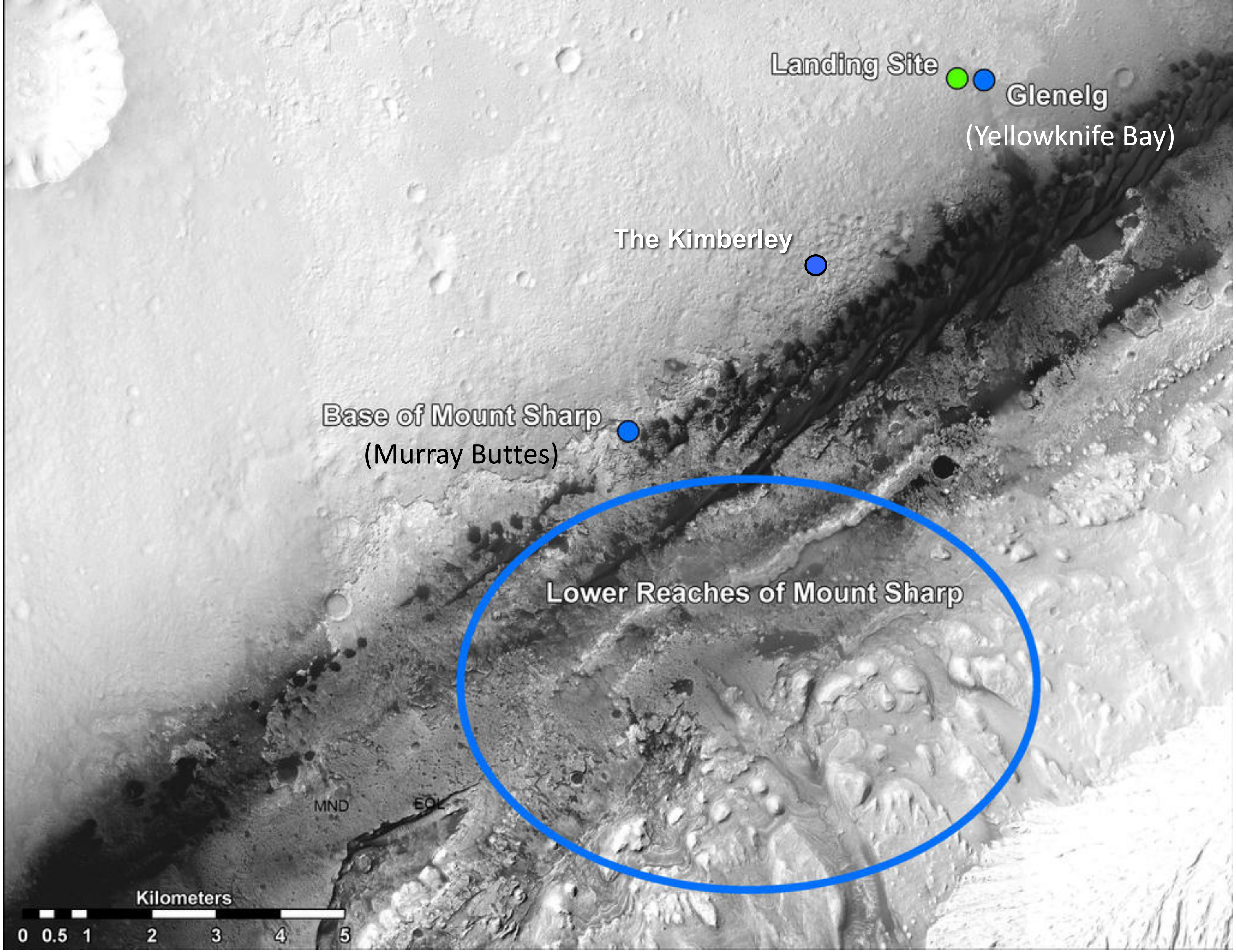
- This is the first-ever detection of a martian organic chemical.
- It took many analyses of rocks and soils, as well as additional analyses of blanks and calibration standards on Mars and on Earth, in order to verify this discovery.
- SAM detected simple hydrocarbon molecules in which some of the hydrogen was replaced with chlorine. This could have happened on Mars, or within the instrument, through reaction with perchlorate compounds that are known to be widespread on Mars.
- Simple organic molecules do not require biology for their formation. However, they are building blocks of life. More importantly, we now can study what environments preserve organics on Mars' surface, increasing our ability to search for other life-related materials.



NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS

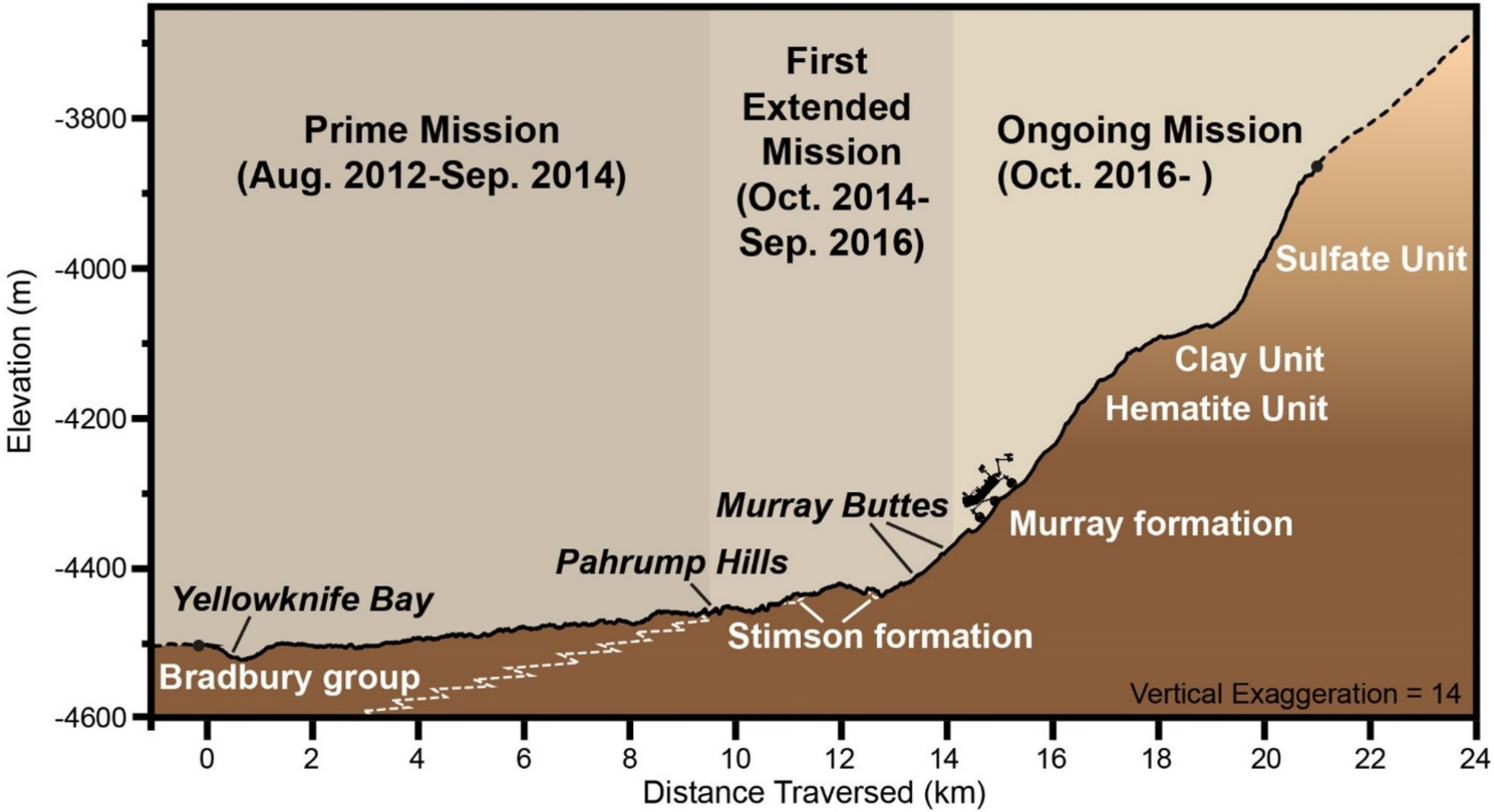


An illustration of lake partially filling Gale Crater. If such a lake existed for millions of years, it would have required a more humid climate and active hydrological cycle.

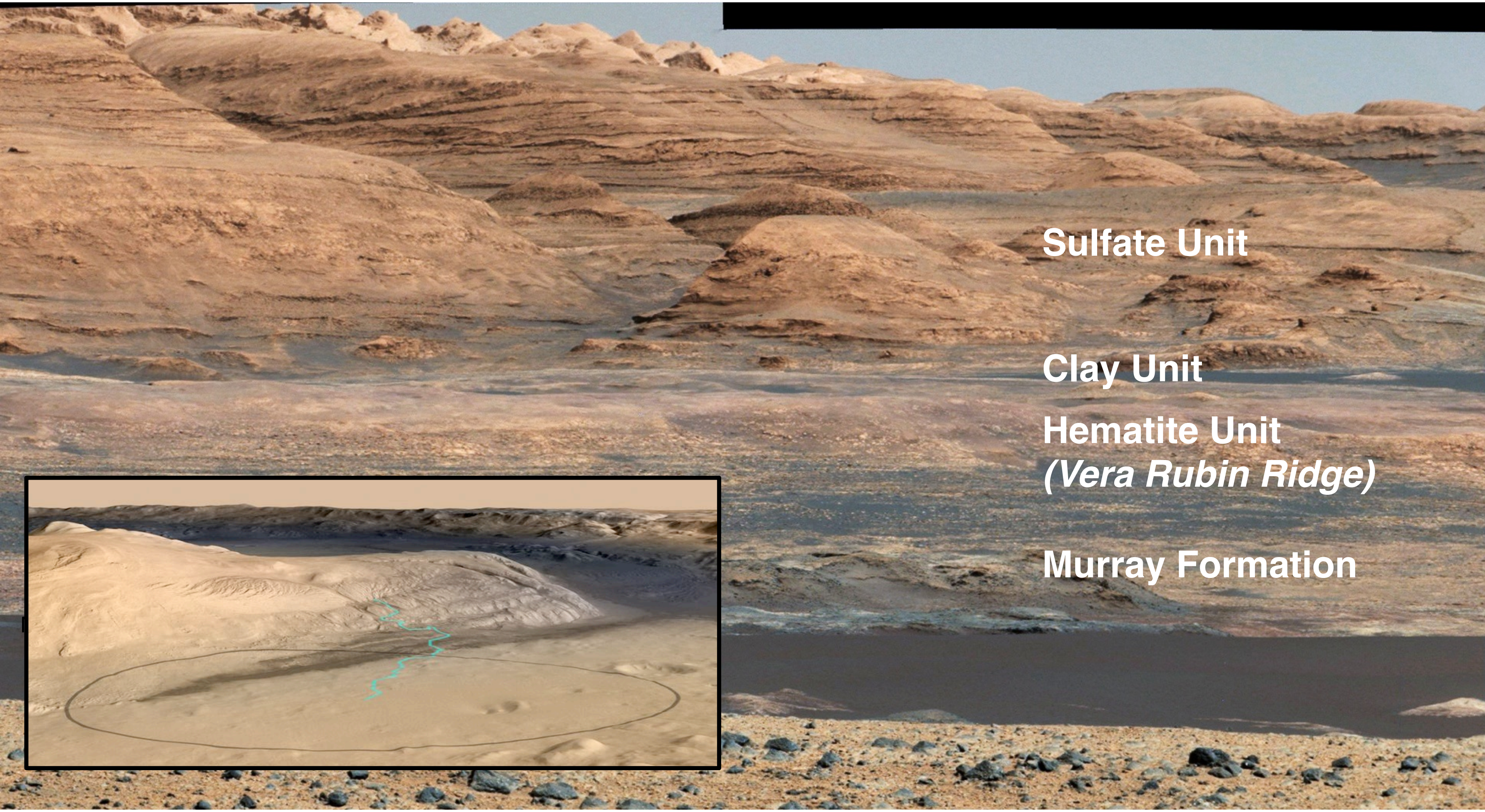


NASA/JPL-Caltech/Univ. of Arizona

Curiosity's ultimate goal is to explore the lower reaches of the 5-km high Mount Sharp

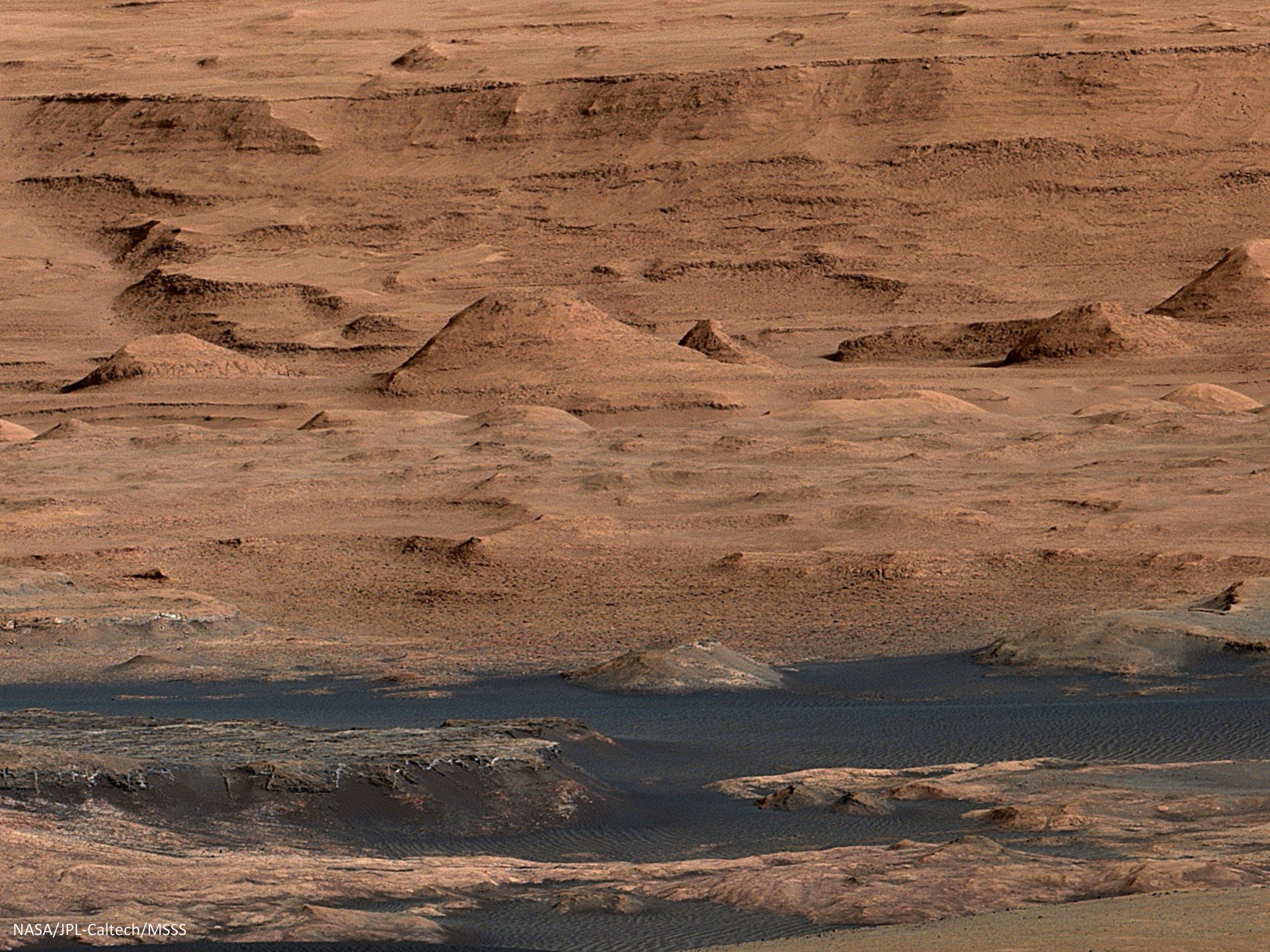


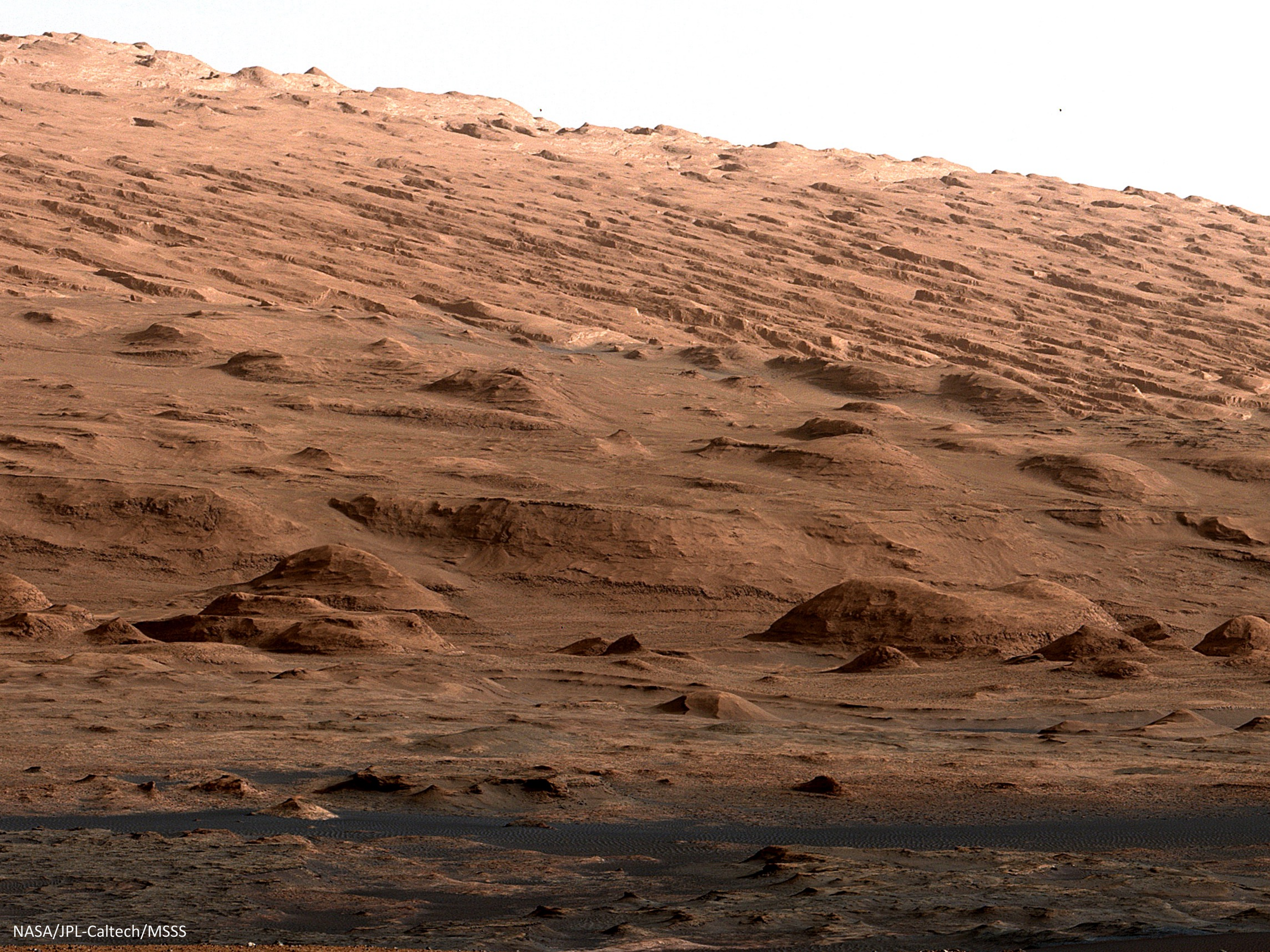
Curiosity is more steeply climbing Mount Sharp in the second two-year extension of its mission



NASA/JPL-Caltech/MSSS

Curiosity's Extended Mission will explore Mt. Sharp, with an emphasis on understanding the subset of habitable environments that preserve organic carbon

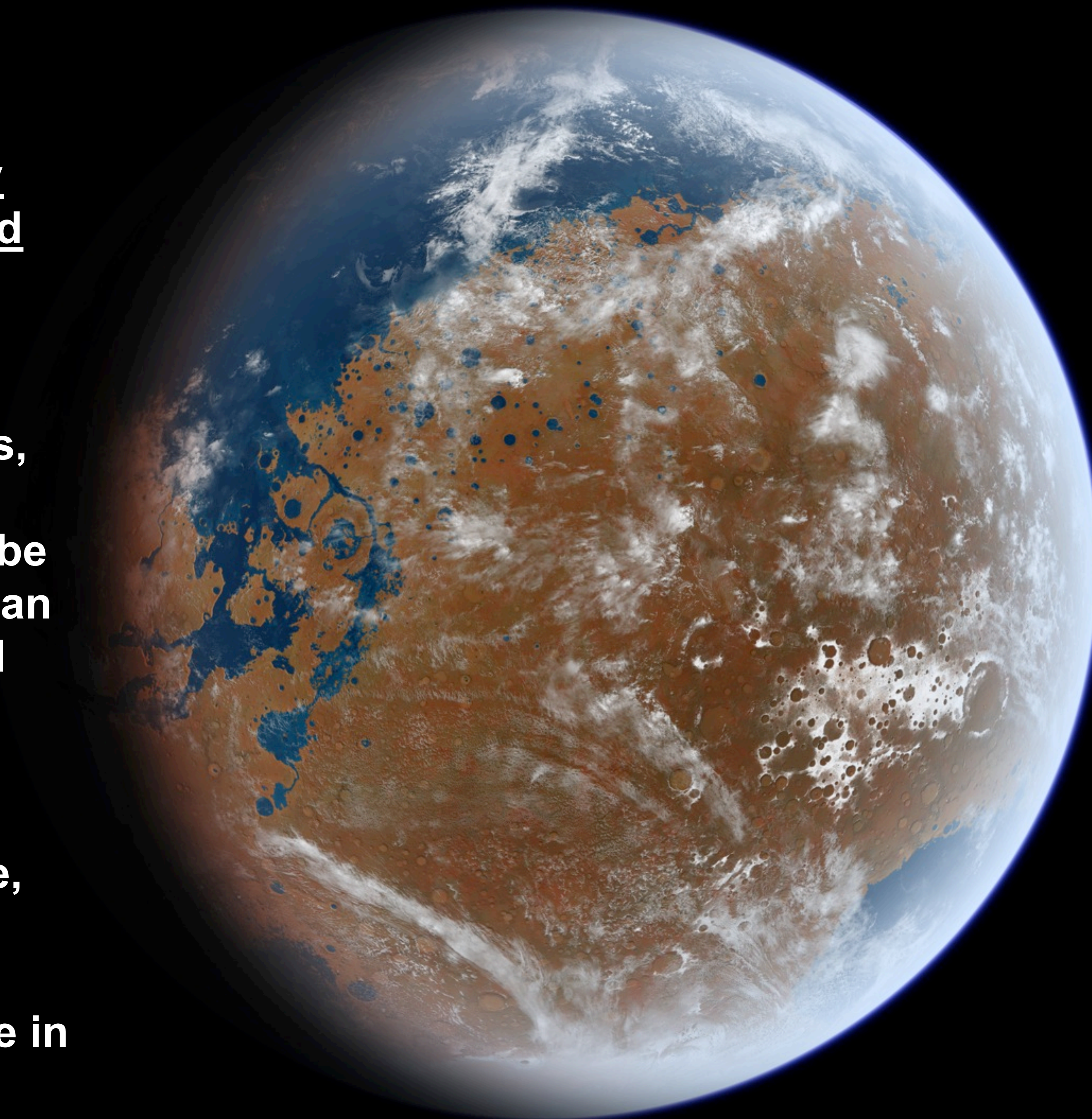

NASA/JPL-Caltech/MSSS

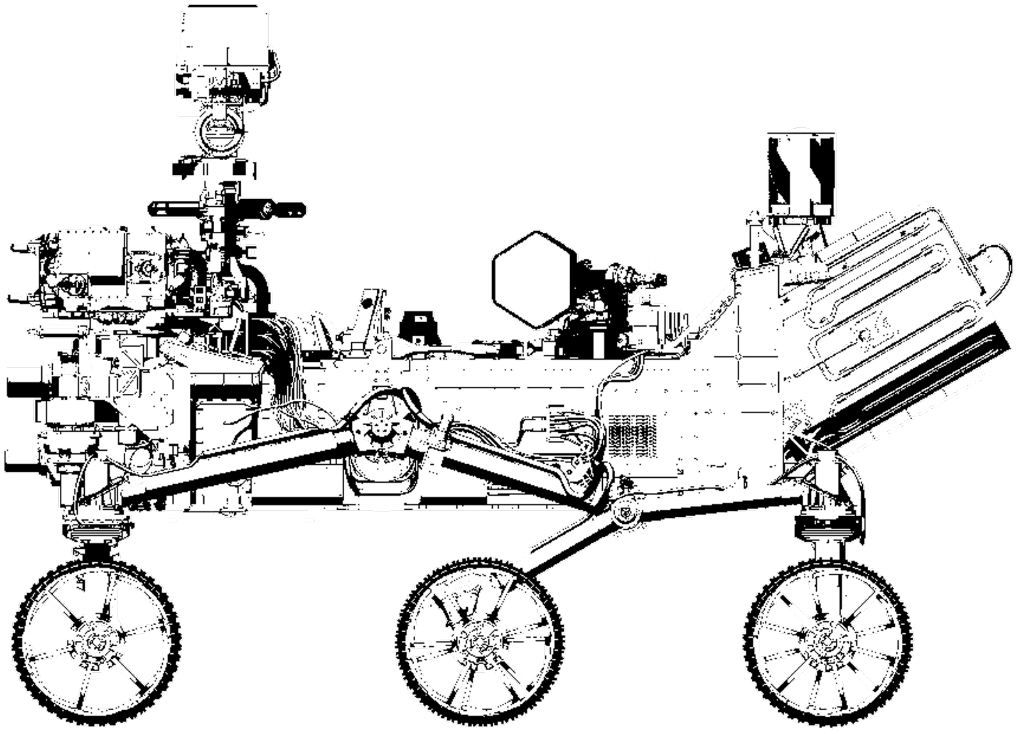

NASA/JPL-Caltech/MSSS

Mars exploration results are strong evidence that early Mars was warm and wet.

Aqueous minerals, high silica deposits, long-lived lakes in Gale Crater would be possible only with an active hydrological cycle and other bodies of water.

Mars was habitable, could have been inhabited, may be today, and could be in the future.



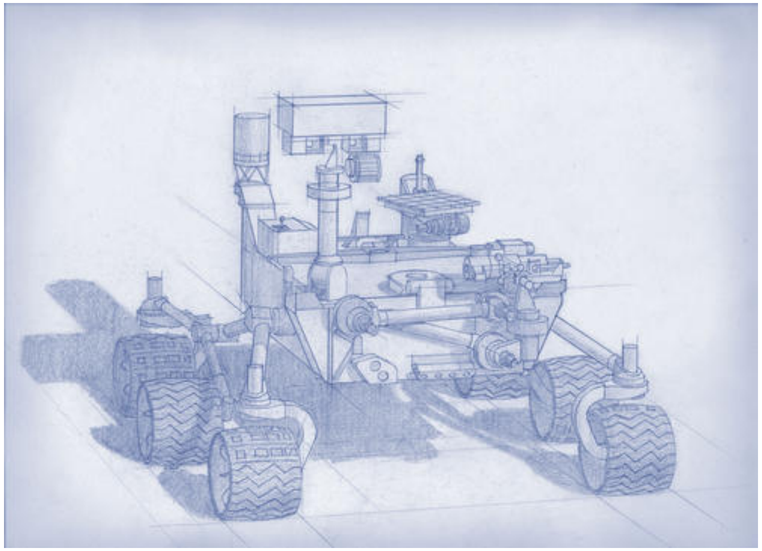


MARS 2020

Project Overview

Salient Features

- *Category: 1*
- *Risk Class: A-tailored*
- *Directed, JPL in-house implementation*
- *High heritage MSL design*
- *Modifications only as necessary to accommodate new payload and Sampling / Caching System (SCS)*
- *Planetary Protection Category V per Program direction*



Science (https://mars.nasa.gov/mars2020/mission/science/objectives/)

- *Characterize the processes that formed and modified the geologic record within a field exploration area on Mars selected for evidence of an astrobiologically-relevant ancient environment and geologic diversity.*
- *Perform the following astrobiologically relevant investigations on the geologic materials at the landing site:*
  1. *Determine the habitability of an ancient environment.*
  2. *For ancient environments interpreted to have been habitable, search for materials with high biosignature preservation potential.*
  3. *Search for potential evidence of past life using the observations regarding habitability and preservation as a guide.*
- Assemble rigorously documented and returnable cached samples for possible future return to Earth.
- *Contribute to the preparation for human exploration of Mars by making significant progress towards filling at least one major Strategic Knowledge Gap (SKG).*

Mission Overview

LAUNCH

- Atlas V 541 vehicle
- Launch Readiness Date: July 2020
- Launch window: July/August 2020

CRUISE/APPROACH

- ~7 month cruise
- Arrive Feb 2021

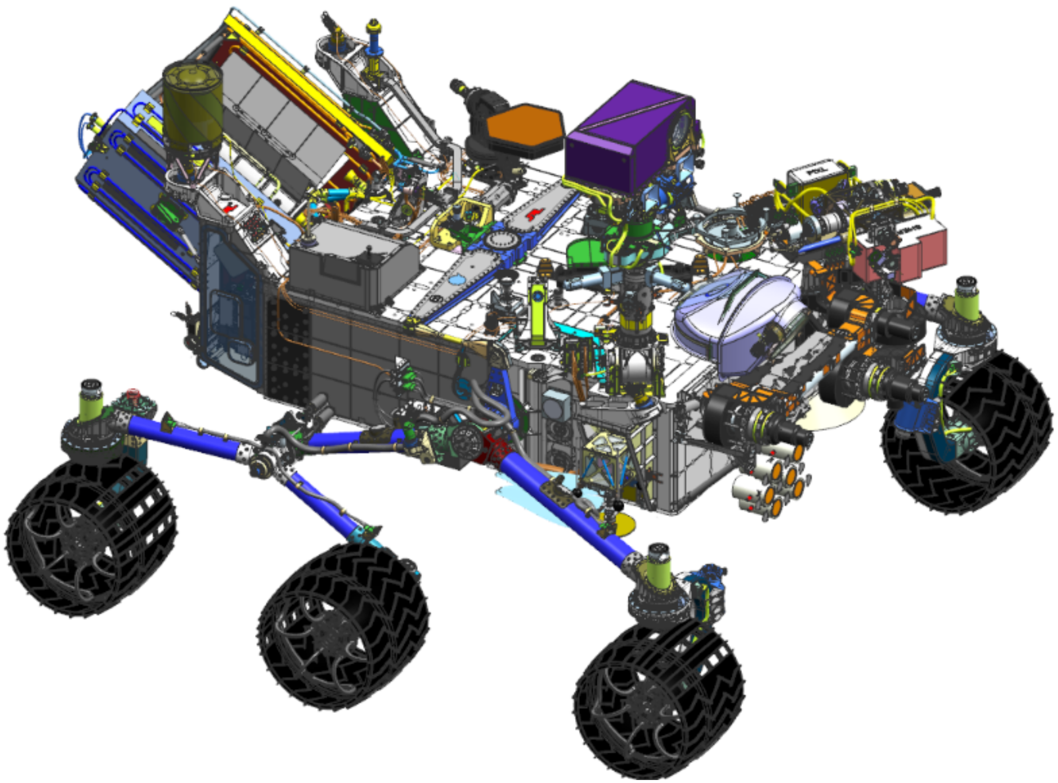
ENTRY, DESCENT & LANDING

- MSL EDL system (+ Range Trigger and Terrain Relative Navigation): guided entry and powered descent/Sky Crane
- 16 x 14 km landing ellipse (range trigger baselined)
- Access to landing sites ±30° latitude, ≤ -0.5 km elevation
- Curiosity-class Rover

SURFACE MISSION

- 20 km traverse distance capability
- Enhanced surface productivity
- Qualified to 1.5 Martian year lifetime
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

Mars 2020 Rover Concept



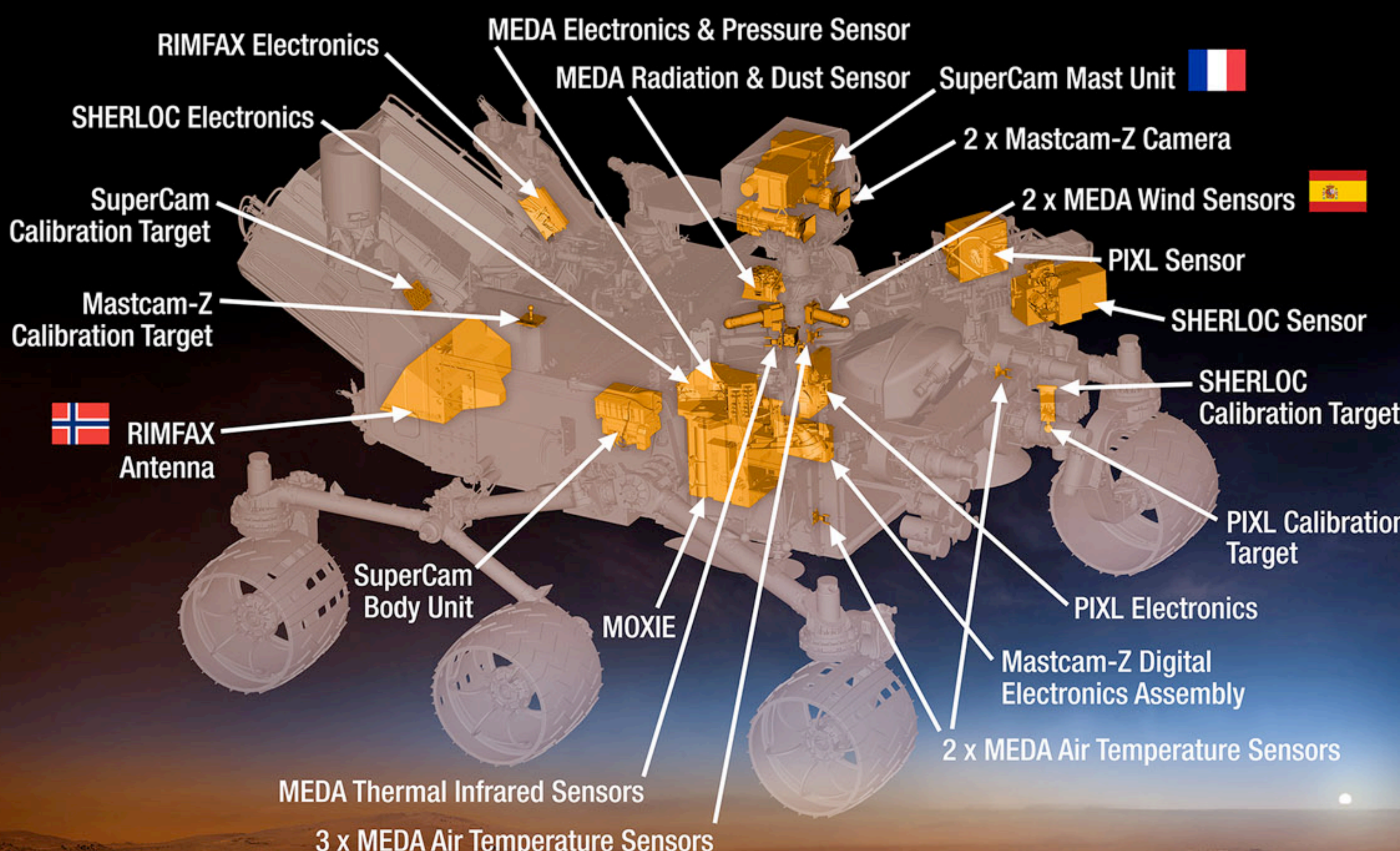
Stays the Same as MSL

- Avionics
- Power
- GN&C
- Telecom
- Thermal
- Mobility

Changed

- New Science Instrument Suite
- New Sampling Caching System
- Modified Chassis
- Modified Rover Harness
- Modified Surface FSW
- Modified Rover Motor Controller
- Modified Wheels

Mars 2020 Rover



https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA19672

THANK YOU!

QUESTIONS?